# Manitoba's Tree Improvement Strategy

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February, 1991

Manitoba
Natural Resources

91-05780/



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Cover Photograph: White Spruce plus tree selected in the Duck Mountains. Selection Criteria: straight stem, above average volume growth, excellent branch pruning, horizontal branch angle, compact crown and no indication of disease damage.

## SUMMARY

The objective of Manitoba's tree improvement program is to increase the yield and quality of wood produced from plantations through the development of genetically improved planting stock. The program is being implemented by establishing operational tree improvement programs as co-operative efforts with Forestry Canada and industry, and by increasing the involvement of regional staff.

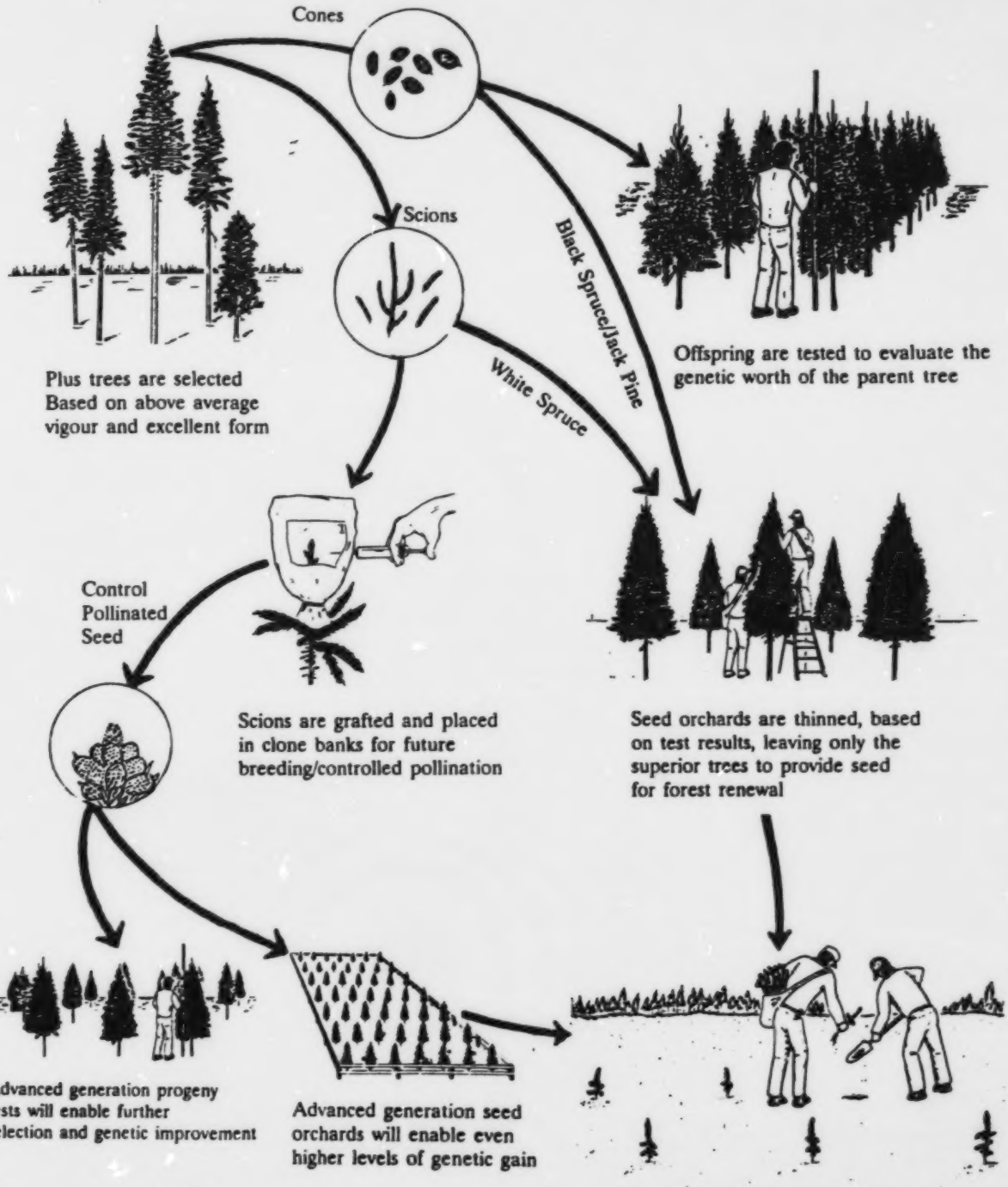
With the increased involvement of field staff it was imperative that a strategy be prepared to describe and direct program development from its onset. This document details the interim measures; breeding alternatives and rationale for recommended approach; and the recommended implementation schedule, based on current capabilities, for the three primary species black spruce (Picea marianna (Mill) B.S.P.), white spruce (P. glauca (Moench) Voss) and jack pine (Pinus banksianna Lamb).

The approach used to breed genetically improved trees is similar to the approach used for cereal crops. Breeding zones, similar to plant hardiness zones, are established across Manitoba for each species. A large number of trees with excellent form and vigour are selected in natural forest stands across each breeding zone. These "plus" trees are then evaluated by planting seed from them on uniform test sites to identify the genetically superior trees. Seed orchards are also established from the original plus trees and are rogued based on the test results leaving only the superior trees to provide seed for genetically improved planting stock. The expected levels of gain in volume production will be 6% after the orchards initial roguing and 12 to 15% after the final roguing. A repeated cycle of selection evaluation and production will occur in subsequent generations enabling further improvements in wood quality and yield.

Although the general concepts are similar, different breeding strategies are recommended for each tree species. The strategies are based on the pattern and level of genetic variation for the species, the potential for improvement of economically important traits, the amount of seed required for the planting program, and the silvical characteristics of the species (i.e. age of flowering, seed retention, even versus uneven aged stands, ability to be vegetatively propagated).

If the tree improvement program is implemented as identified in the proposed implementation schedule, by 1995 all first generation tests and seed orchards will be established and 30% of the jack pine planted in forest renewal programs will be from improved seed. By the year 2005, 70% of all black spruce, 50% of all white spruce and 100% of all jack pine planted in Manitoba will be from improved seed.

# ILLUSTRATION OF THE TREE IMPROVEMENT PROGRAM




Drawings by J. Teichroeb

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## ACKNOWLEDGEMENTS

I would like to thank the following people for their detailed and helpful review of this document's initial draft: Tim Boyle and Dr. Kit Yeatman of Forestry Canada at the Petawawa National Forestry Institute; Jim Coles of the Ontario Tree Improvement Council at the University of Guelph; Dr. Narinder Dhir of the Alberta Forest Service; Dr. Jerry Klein of Forestry Canada at the Northern Forest Research Centre; Dr. Kris Morgenstern of the University of New Brunswick; Tim Mullin formerly of the Nova Scotia Department of Lands and Forests; and Albert Nanka of Forestry Canada at Winnipeg, Manitoba.

I also want to thank the staff at the Manitoba Forestry Branch, Abitibi-Price Inc. and Repap Manitoba Inc. who reviewed the document and contributed their comments. I especially appreciate the editorial review conducted by Dan Bulloch and Dr. Richard Westwood, and Dianne Arjoon's patience in retyping the entire document after the computer got a little hungry.

# INTRODUCTION

Forestry is one of Manitoba's primary industries. It is the sixth largest employer in the province with over 5,200 people directly employed. Within Manitoba's manufacturing sector, forestry is currently ranked fifth with the gross value of forest products shipped exceeding $450 million dollars in 1988 (Province of Manitoba, 1990). Although wood supplies are currently sufficient to meet industry requirements, close-at-hand supplies are becoming scarce. This is reflected in the excessive distances that industry must haul timber in order to supply it's mills.

Intensive forest management of highly productive sites is essential if industry is to maintain a supply of close-at-hand wood and thereby remain competitive in existing markets. In recognition of the need for intensive forest management, the Canada-Manitoba Forest Renewal Agreement was signed in 1984. With the signing of the Agreement, forest renewal expanded from an annual planting program of 4.3 million seedlings in 1984 to 15.7 million in 1988. In addition, to meet an anticipated future demand of 20 million seedlings per year, a new provincial nursery was built at Clearwater Lake and the existing nursery at Hadashville was expanded.

Currently over 10 million dollars in provincial and forest industry funds are spent annually on Manitoba's forest renewal program. The majority of seed currently being used in the forest renewal effort is from general collections within individual seed zones. If silviculture programs in Manitoba are to maximize the growth of artificially regenerated areas, the use of genetically improved seed is essential. A balanced silviculture program is crucial, as no known silvicultural treatment can offset the use of seed from poor parentage.

In recognition of the above it was recommended that a review of the existing tree improvement program can be completed and a strategy developed to meet the following objectives:

1. To establish interim measures which will ensure that good quality, source identified seed is used until improved seed becomes available.

2. To increase the yield and quality of wood produced from plantations through the development of genetically improved planting stock.

The following constraints and opportunities had to be considered when determining options for program delivery.

a) Constraints

--no additional permanent staff positions to assist with program implementation are currently available.

--no further expansion of growing facilities was likely to occur.

--no additional funds were available from the 1984/89 renewal agreement for the implementation of a spruce program and the approval of large increases in the ongoing budget for the tree improvement program was unlikely.

--further delays in initiating a program will impair the selection program due to many of the best stands being harvested and increase the possibility of industry establishing their own program without provincial input.

b) Opportunities

--increased involvement of Regional and industrial staff was possible.

--Pineland Nursery staff could be responsible for producing tree improvement crops out of the existing tree improvement facility.

--Forestry Canada involvement with the jack pine improvement program was guaranteed for the term of the existing renewal agreement.

--a new 5 year renewal agreement will be signed in the future and new tree improvement projects could be proposed as a component of the agreement.

Based on the above it was decided to promote the establishment of operational tree improvement programs as co-operative efforts with industry (Manitoba Tree Improvement Co-operative) and to increase the involvement of regional staff. If field staff involvement was to be increased it was imperative that a strategy be prepared to describe and direct program development from its onset.

This document details the recommended interim measures; breeding alternatives and rationale for recommended approach; and the recommended implementation schedule, based on current capabilities, for the three primary species black spruce (Picea marianna (Mill) B.S.P.), white spruce (P. glauca (Moench) Voss) and jack pine (Pinus banksianna Lamb.). Improvement of red pine (Pinus resinosa Ait.) is not recommended due to the lower level of genetic variation within the species. The breeding strategy for hybrid poplar will be developed when there is sufficient interest in the artificial

regeneration of poplar to warrant an improvement program.

Long range planning must be flexible enough to facilitate changes in demand, and to capitalize on the results of new research and technological advances. Therefore, the overall program direction will be formally reviewed on a five-year basis and the implementation schedule updated on an annual basis. The specific operational guidelines for the establishment and management of the various tree improvement projects will be detailed in a Tree Improvement Manual as a part of the Manitoba Silvicultural Manual.

## HISTORY AND CURRENT STATUS OF TREE IMPROVEMENT PROGRAMS IN MANITOBA

The first tree improvement program in Manitoba was initiated in 1967 by Forestry Canada, previously the Canadian Forestry Service. The program's objective was to produce genetically improved jack pine seed for planting programs in the Pineland-Bisset (Eastern Breeding District) and the Duck-Porcupine Mountain (Central Breeding District) areas of Manitoba (Klein, 1982). The program involved selecting over 200 trees which had above average height and excellent form (plus trees) per Breeding District, collecting branchlet (scion) material for grafting and placement in a clone bank, and collecting cones for the establishment of four family test plantations across each Breeding District. To date 5, 10 and 15 year growth measurements have been taken on the Eastern Breeding District family tests. Based on the 10 year measurements, seed collection areas were identified and the 5 top ranked family members from the 40 top ranked families were crossed to establish a seedling seed orchard in 1988. Trees and families are ranked based on their volume (height and diameter), stem straightness and branching habits. The 15 year measurements of the Eastern Breeding District family tests and the 10 year measurements to the Central Breeding District family tests are currently being analyzed.

The initial program established by Forestry Canada did not sample jack pine populations in the Interlake or Northern Regions of Manitoba due to the small planting programs in these areas. However, with recent increases in planting activity in these areas, a lower cost tree improvement program was approved in 1984 under the Canada-Manitoba Forest Renewal Agreement. The approach involved selecting 10 plus trees from each of 32 sources stands and collecting cones to establish a mass selection orchard (Klein, 1983). The mass selection orchard is planted at close spacing and is selectively thinned every 3 to 5 years leaving only the best trees to cross pollinate. The Northern Region's two mass selection orchards were planted in 1986 and the Interlake Region's orchard was planted in 1987.

The first generation jack pine orchards which are currently in place are of sufficient size to supply 70% of the forecasted seed requirements for planting programs in Manitoba. The second generation improvement program for the Eastern District is expected to commence within the next five years.

The provincial government embarked on the establishment of a tree improvement program in the early 1970's by establishing local provenance tests for 17 jack pine (Segaran 1978a), 15 white spruce (Segaran 1977), and 20 black spruce (Segaran 1978b) seed sources located across the province. Other provenance trials established in Manitoba as co-operative provincial-federal projects included a range-wide black spruce test and tests of exotic species including Scots Pine (Pinus sylvestris), Ponderosa Pine (P. ponderosa Laws) and Norway Spruce (Picea abies (L.) Karst).

Hybrid poplar trials were established by the province in 1976. The objective was to test the Hybrid Populus Walker clone (Synonym Populus 44-52) on five diverse sites across the province to determine its applicability, growth potential and optimum rotation age. Populus Walker was developed in 1944 at the PFRA Tree Nursery, Indianhead, Saskatchewan, as a cross between a female clone of Populus deltoides Bartr. and an unknown male clone. Based on the volume tables produced at five year after planting, the expected pulpwood rotation was 8 - 10 years (Segaran and Rathwell, 1978). The previous lack of market for poplar restricted further planting of this clone. However, the recent interest in utilizing poplar for pulp, particle board and orientated strandboard has resulted in a renewed interest in the use of hybrid poplar in Manitoba.

The first white spruce seed orchard was established in 1980 from 144 grafts of 10 white spruce plus trees which were intensively selected across the province. In addition, a white spruce seedling seed ochard was established in 1981 using seed from the 15 local provenance sources. Two small black spruce seedling seed orchards were established in 1981 and 1984 at Pineland Nursery and Lake St. George using seed from 18 of the local provenance sources (Gillis 1985). By 1988 0.6 hectares of black spruce seed orchards and 0.4 hectares of white spruce seed orchards were established in the province.

In summary, the jack pine orchards which are in place will eventually supply 70% of the forecasted seed requirements for planting stock. However, the existing spruce orchards will only supply two percent of the forecasted seed requirements. In addition, due to problems with the smaller number of selections, their wide distribution (up to 6° in latitude) and a lack of testing it is not recommended that seed from the spruce orchards be used. There is therefore an urgent need to establish black spruce and white spruce tree improvement programs across the province.

## PROGRAM JUSTIFICATION

Why invest in establishing a tree improvement program? If the forest industry in Manitoba is to remain competitive in existing markets an adequate supply of reasonable priced wood must be available. It has been stated that one of the most cost effective methods of meeting the requirement is to intensively manage productive forest sites close to the mills. The use of genetically improved planting stock in conjunction with other intensive silvicultural practices will result in increased plantation survival and yield, shortened rotations and improved product uniformity and quality.

Tree improvement programs involve relatively large expenditures over a long time period prior to achieving the actual benefits. Therefore a review of the numerous economic analysis which have been conducted on tree improvement programs helps to:

1) justify the high funding requirements during program initiation,

2) identify the subsequent maintenance, measurement and management funding levels required for program completion,

3) identify sensitive areas which have an impact on the programs cost efficiency and thereby influence the program strategy.

Does tree improvement pay? Economic analysis conducted in the Southern States (Davis, 1969; Bergman, 1969) and Canada (Carlisle and Teich, 1971) have shown that a 3-4% gain in volume production would justify investing in tree improvement. The expected levels of gain in volume production will be 6% after the orchards initial roguing and 12 to 15% after the final roguing. Based on the initial results of jack pine (Klein, 1982) and white spruce (Kiss, 1987) breeding programs in Canada, the above estimated levels of gain are conservative. A recent review of tree improvement programs across the United States calculated an average benefit-cost ratio of 8.2 utilizing a 7$^{1}/_{8}$% discount rate (Risbrudt and McDonald, 1986).

In addition to volume growth, gains will also be made in stem straightness, branch angle and wood quality, in particular specific gravity. Improvement of these traits will increase product quality and uniformity but the economic value of the gains is difficult to quantify. Weir and Zobel (1981) determined that pulp produced from only straight trees resulted in a 1% increase in pulp yields due to the reduced level of unusable reaction wood in the tree. Roddy (1981) determined that this improvement would increase the Prince Albert pulp mill's revenues by over $1 million per year without even considering the additional reductions in hauling and mill costs.

In summary, tree improvement can definitely pay. However, tree improvement specialists have generally agreed that to maximize the programs profitability and cost efficiency the following two factors should be considered when developing a tree improvement strategy:

1) All costs must be carried the length of the program. Therefore it is essential to minimize initial costs where returns are low. To meet this objective the following recommendations are made:

--for low heritability traits like volume growth, the selection intensity will be decreased during the plus tree selection program and increased in the family tests.

--all first generation seedling seed orchards will be established on sites which do not require a permanent irrigation system.

--fencing of tests and orchards will be restricted to species and areas where the potential for browsing damage is high.

In addition it is essential to shorten the program's time frame, or breeding cycle , in a manner which will enable achieving the maximum gain per unit time. This is one of the reasons for recommending that all tree improvement stock be grown in larger containers under high pressure sodium lights. The use of larger, sturdier planting stock is expected to increase the survival and development of the family tests. This would help to reduce the time period required before reliable information is available from the tests.

2) Economies of scale should also be considered when developing a tree improvement program as many of the costs are fixed. When these costs are applied against a small annual planting program the returns are often insufficient to justify the large investments in a tree improvement program. Based on the above, and existing constraints in funding and staffing, it is recommended that intensive seed orchard programs with family tests only be established in breeding zones where the planting program for the particular species is forecasted to exceed 1.5 million seedlings per year. For breeding zones with smaller planting levels, a lower cost improvement program will be considered.

## EXPLANATION OF FOREST GENETICS PRINCIPLES AND TREE IMPROVEMENT PRACTICES

Forest genetics is defined as the study of hereditary variations in trees. Tree improvement involves the application of forest genetics principles to practice. In Manitoba these principles will be applied through the establishment of operational tree improvement programs as a component of the provincial or; industrial co-operators silviculture program. In order to implement this program an understanding of basic forest genetics principles and terminology is essential.

### 1. VARIATION

It is a prerequisite of any tree improvement program that trees exhibit genetic variation in economically important traits. A great deal of variation does exist for most tree species, occurring at a number of levels. As a result, a tree improvement strategy must consider:

--the overall pattern of genetic variation and how it is distributed within each species.

--how desirable traits can be captured from the existing variation and reproduce for use in the reforestation programs.

--how the genetic variation may ultimately be recombined to obtain additional genetic gain in future generations.

Genetic variation within species occurs between:

a) widely separated geographic populations
b) populations within a physiographic region
c) individual trees within a population.

#### A) Geographic Variation

Geographic variation is the result of a species adapting to the natural selection pressures of the environment in which it has evolved. Differentiation usually occurs continually along an environmental gradient related to factors such as climate, latitude and elevation. This pattern of continuous variation along a gradient is referred to as clinal. It is the predominant pattern of genetic variation for Manitoba's major tree species.

Ecotypic (discontinuous) patterns of variation may also exist. This is due to isolated populations inter-breeding and becoming genetically distinct ecotypes. Teich and Holst (1974) reported that white spruce ecotypes may exist between populations growing on calcareous and acidic soils in Eastern Ontario. Isolated populations in the Spruce Woods area of Manitoba may have also developed in separate ecotypes.

The level of genetic variation occurring between widely separated geographic populations is determined through provenance tests. The results of these tests are utilized in setting basic guidelines to guard against losses in yields due to seed being moved too far from its adapted source. Morgenstern and Roche (1969) have shown that the transfer of seed by three degrees of latitude or 300 metres of elevation could result in a 6-17% loss in yield. These guidelines and the general patterns of genetic variation for the various species have been used in determining the seed zones for Manitoba (Calvert, 1973; Segaran, 1979; Dojack, 1990).

### B) Population Variation

Population Variation is the genetic differentiation between stands within a physiographic region where environmental influences are similar. Provenance tests, stand tests and/or family tests may all be used to identify better populations or stands. Once identified, these stands would be used to establish seed collection or seed production areas. For example the 10 year growth data from the jack pine family tests in the Eastern Breeding District of Manitoba (Klein, 1982) has been used to identify better stands. These stands have subsequently been established as seed collection areas.

### C) Individual Tree Variation

Individual Tree Variation is the variability which exists from tree to tree within a stand. The level of variation will differ by species and trait but generally is quite large taking the form of a normal distribution. It is primarily this variability which is used as the basis for the selection, evaluation and subsequent breeding of individuals in tree improvement programs.

## 2. PLUS TREE SELECTION - ASSEMBLY OF BREEDING STOCK

The plus tree selection program is one of the first steps in an intensive tree improvement program. It is often referred to as the assembly of breeding stock because it involves the collection of material from natural populations to form the foundation of the breeding program. It is a crucial step because a program built on a weak foundation will never meet its full potential.

A plus tree is an individual tree which appears to be superior to the trees around it based on visual or measured comparisons of selected traits. Two terms used to describe the individual tree are phenotype and genotype.

Phenotype is the visual appearance of the tree. Therefore when selecting plus trees a person is selecting phenotypically superior trees or trees which appear to be superior. However, the trees genetic superiority is unconfirmed. A trees phenotype is the result of not only its genetic make up but also the environment it has grown in. Thus Phenotype = Genotype + Environment.

Genotype is the genetic makeup or constitution of the tree. The identification and breeding of superior genotypes is the goal of a tree improvement program.

Heritability is an index which indicates the portion of the variation existing amongst individuals which is due to genetic influences as opposed to environmental influences. Therefore heritability values represent estimates of the degree of genetic control for a particular trait.

Genetic Gain is the improvement made in the average performance of the offspring from selected individuals as compared to the average performance of the original population. The amount of gain (G) achieved for a particular trait, like height growth, depends on the trait's heritability ($H^2$), the selection intensity (i) used and the amount of phenotypic variation (Qp) existing in the population. This is shown in the formula: $G = H^2 \times i \times Qp$.

The following examples will help clarify this relationship:

1. Trait = Stem Straightness in Jack Pine. This trait has a moderate to high level of heritability and a high level of variation. Therefore intensively selecting plus trees with straight stems will likely result in substantial improvement or gains.

2. Trait = Branch Angle in Black Spruce. This trait has a moderate to high level of heritability but a low level of variation as black spruce typically has horizontal branch angles. Therefore this trait will be ranked low in a black spruce plus tree selection program as there is little room for improvement.

3. Trait = Height Growth in Black Spruce. This trait has a low level of heritability and a relatively high level of variation. Therefore gains in height growth will require high selection intensities. However because of the low heritability levels accurate selection is more complex.

As illustrated in the above examples. selection intensity is the only factor in the equation that the tree breeder may control to achieve genetic gain. However, selection

occurs in two phases of the program namely during plus tree selection and family test evaluation. The selection intensity used in these two phases will depend on the heritability values for the trait. For example, with highly heritable traits, like stem straightness, intensively selecting plus trees in wild stands is an effective method of achieving gain as the probability of selecting good genotypes is relatively high. However, for low heritability traits like height growth, intensive plus tree selection is inefficient as environmental variation is large and the controlling factor. Therefore selection involves a combined approach using low intensity selection of plus trees in wild stands and higher intensity selection based on family performance on uniform test sites. This approach, called family selection, involves the selection or rejection of the entire family of seedlings from one plus tree based on the mean value of the family in the tests. Family selection for low heritability traits like height growth has been shown to be more cost effective than intensive individual-tree selection for black spruce and jack pine (Morgenstern et al. 1975).

## 3. GENETIC TESTS - EVALUATION AND FURTHER SELECTION

Genetic tests are plantations established to:

--evaluate the genetic worth of individuals based on the performance of relatives

--select individuals for advanced generation programs

--demonstrate gains achievable for program justification.

Genetic tests are referred to as family tests or progeny tests depending on the origin of the material and its purpose. Both terms refer to a group of related individuals which have one or more parents in common. The proper naming of genetic tests also depends on how the seed was pollinated.

i) Open-pollinated families have one parent in common and the other parents unknown (wind pollinated). The seed collected from a plus tree is considered an open-pollinated family.

ii) Half-sibs are a group of siblings with only one parent in common (control pollinated).

iii) Full-sibs are a group of siblings with both parents in common (control pollinated).

A number of test sites are established in each breeding zone in order to sample a range of planting sites. Use of only one site may result in the selection of a family/individual which responds only on that particular site. The objective of the first generation tests is to avoid this form of genotype-environment interaction and instead

select families/individuals which are broadly adapted to the range of planting sites.

Test sites are established on typical, productive planting sites and are intensively cultivated and maintained to minimize environmental variability. Well prepared test sites have been shown to increase the survival, growth and expression of genetic differences in jack pine (Klein pers. comm. 1987) and white spruce (Kiss, 1981).

## 4. PRODUCTION ORCHARDS

Production orchards are plantations of selected individuals established for the production of large quantities of genetically improved seed or vegetative propagules in the shortest possible time. Orchards usually contain numerous families or clones planted at close spacing. This is to enable the eventual removal of poorer individuals based on the results of the genetic tests. There are a number of types of production orchards:

i) Seedling seed orchards are established with seedlings which are usually from the seed of selected parents. The mass selection orchards discussed in this document are a form of seedling seed orchard. Seedling seed orchards are best suited to species like jack pine and black spruce due to:

--the earlier age at which seedlings are sexually mature and produce cone crops.

--the lower potential for gain in volume growth in the first generation, due to low heritability, does not justify the higher establishment cost of a grafted orchard.

--the potential elimination of some jack pine genotypes due to graft incompatibility.

--the slow development of large cone bearing crowns with grafted jack pine.

ii) Clonal seed orchards are established with grafts or rooted cuttings thereby replicating the exact genetic identity of the selected individuals. Clonal seed orchards are best suited to species like white spruce due to:

--sexual maturity from seed does not occur until trees are 15-20 years old with optimal production not occurring until 40 years. However, grafted scions retain the plus trees sexual maturity and thus can produce abundant seed a few years after grafting.

--the heritability levels and degree of variation in stem quality traits are higher. White spruce is primarily a lumber species and therefore improvement of these traits is especially important.

iii) Container seed orchards can be established with seedlings, grafts or rooted cuttings. The stock is maintained in large pots within plastic covered houses. The potted stock is intensively cultured to promote early, consistent and abundant flowering. Container orchards could be used for all three species but in Manitoba they are best suited to grafted white spruce due to:

--its ability to produce a large number of cones in a small space.

--the lower seed requirements due to a smaller annual planting program.

--the ability to control environmental conditions reduces problems that conventional white spruce orchards have with cone crop periodicity and inconsistent flowering amongst clones.

iv) Hedge orchards are established with seedlings or rooted cuttings from selected individuals. The plants are repeatedly pruned to a low height in order to produce numerous juvenile shoots for propagation as rooted cuttings. This approach to clonal forestry is currently most applicable to black spruce and white spruce due to the ease at which they may be propagated from rooted cuttings.

## 5. BREEDING ORCHARDS - CLONE BANK

Breeding orchards are usually established with grafts of selected trees primarily to obtain pedigreed seed from controlled pollinations. These orchards may be soil based (ie. clone banks, breeding gardens) or in large pots within plastic covered houses (i.e. breeding halls). They are usually established at a nursery to facilitate intensive management and controlled pollination programs. The individuals used in the controlled crosses are termed the breeding population.

In any particular generation the production population in the seed orchards may be relatively small (50 families) due to intensive roguing. However, a large breeding population must be maintained to ensure that an adequate genetic base is maintained in future generations. A large genetic base is maintained through repeated selection within the tests and the periodic introduction of new selections often originating from source identified plantations.

## INTERIM MEASURES FOR SEED SOURCE CONTROL

Tree improvement is a long term venture. Even ten years after initiating a program only a small amount of improved seed will be available. Realistically it will take fifteen to twenty years after initiating a program before all seed requirements can be operationally met from orchards. The purpose of interim measures is to ensure that the best possible seed collections are maintained until seed is available from tree improvement programs. In the past field staff have collected seed from identified sources on a number of occasions. However, the intent is to increase this practice to ensure that all seed for stock production is collected from seed collection areas exhibiting above average quality.

The benefits which will be derived from increasing this program of basic genetic management are:

1. The collection of inferior seed will be restricted, resulting in an expected increase in yield, nursery crop uniformity and plantation performance.

2. The collection of seed from stands and individuals within stands, which exhibit excellent stem form and branching characteristics will provide an immediate improvement in the quality of new forests being created. This is due to these traits being more strongly inherited thereby enabling more effective field selection.

3. The original location of seed sources will be known. If planting stock must be transferred outside of its seed zone the transfer distance will be known and results can be monitored.

4. The forecasting, monitoring and protection of cone crops will be improved. Conducting these operations at an intensified level will be more feasible within identified areas versus extensive Management Units.

5. The collection areas and/or adjacent sites will be regenerated with the identified seed source. These areas will serve as bench marks to evaluate the performance of improvement programs, provide sources for future selection and act as gene pool reserves.

## SEED COLLECTION AREAS: SELECTION CRITERIA AND MANAGEMENT

Seed Collection Areas (SCA) are stands exhibiting vigorous growth and above average form, which are harvested to provide a supply of seed. The use of SCAs is most applicable to species which have serotinous cones, namely black spruce, jack pine and red pine. White spruce SCAs may be utilized providing there is excellent co-operation with cutting and cone picking crews as timing is crucial.

The stands selected as SCAs must meet the following criteria:

1. Above average stem form and branching characteristics. The stand must contain predominantly trees with straight stems, no forking and relatively horizontal branch angles. Not all trees within the stand will exhibit the above characteristics, but the overall stand must be above average to ensure that the majority of cones are collected from individuals exhibiting excellent form. If possible, cones should be collected from the best 25% of the trees in the stands. The increased collection costs would be justified by the resulting improvement in form traits. These improvements will be exhibited immediately in production plantations and will result in improved pulp yields and lumber grades.

2. Exhibit vigorous growth. The stand should be well stocked, even aged, within 20 years of maturity and growing on a productive site. Above average growth is not essential as volume growth is under a high level of environmental control and therefore field selection for it is less reliable. Improvement of volume growth will occur through the long term tree improvement program. High graded or selectively cut areas should be avoided.

3. The stand must be accessible to harvesting and cone picking crews when the cones are mature. The stand should also be greater than 10 hectares in size and show evidence of previous cone crops.

In order to maintain an adequate genetic base the number of SCAs established per seed zone should be as follows:

--3 SCAs/Seed Zone for planting programs greater than 2.0 MM annually.
--2 SCAs/Seed Zone for planting programs greater than 1.0 MM annually.
--1 SCA/Seed Zone for planting programs less than 1.0 MM annually.

Only a portion, usually one-third, of each SCA should be cut in a particular year and only in good crop years. Cones should be collected from only the trees exhibiting good form and branching habits. It is therefore essential that the stand be predominantly composed of good individuals.

The division of management responsibilities would be as follows:

a) Region/Industry - selects SCAs, assesses cone crops, arranges the felling and collection of cones.

b) Head Office - prepared annual budgets and assists field staff with the selection of SCAs.

## SEED PRODUCTION AREAS

A Seed Production Area (SPA) is a stand or plantation exhibiting above average form and vigour. It is upgraded by removing undesirable trees and subsequently managed to provide a continuous supply of seed from standing trees.

The establishment, management and cone collection costs for SPAs may be up to 3Xs higher than general collections. Amongst tree improvement specialists there is a difference of opinion on whether or not the increased costs of using SPAs versus SCAs are justified. Based on funding constraints and comments received during the initial review of this report it has been decided that SCAs will be established instead of SPAs. This will enable more funds to be available for the establishment of tree improvement programs.

## REVISION OF SEED ZONES

The establishment of seed zones, to define the geographic area within which the collection and distribution of seed is confined, is a prerequisite to any forest renewal program. Trees adapt to the natural selection pressures present in the environment where they have evolved. Therefore valid seed zones guard against losses in yield, resulting from growth reduction, frost damage and poor survival, which occur when planting stock is transferred to a dissimilar environment.

In 1973 twelve zones were established to govern the movement of seed in Manitoba (Calvert, 1973). The seed zone boundaries were established based on the following criteria:

--zones should not be greater than 2° of latitude nor encompass elevational changes greater than 300 metres.

--the major pattern of genetic variation for black spruce, white spruce and jack pine is clinal following a geographic gradient related to temperature and photoperiod. White spruce has also demonstrated ecotypic, or discontinuous, variation often related to limestone deposits and subsequent pH levels.

--climate, as it is a controlling factor in the distribution of forest trees. Factors considered included: date of last spring frost and first fall frost; frost free period; length of growing season (above 5° C); degree days; mean July, January and annual temperatures; moisture regime (Thornthwaite); and mean annual precipitation.

--vegetation zones, primary forest succession and the range of tree species in Manitoba.

--provincial physiography including major soil zones and the occurrence of permafrost.

--delineation systems used in other provinces.

In 1979 seed zones were established for the three main commercial species in Manitoba (Segaran, 1979). Nine individual seed zones were identified for each species. The zones were based on the previous criteria and variations in the growth rate of two-year old seedlings from different local seed sources. Zone boundaries generally utilized lines of latitude with the aim of restricting seed movement to less than 1½° of latitude.

Although establishing individual seed zones for each species may be justified, a recent analysis of the local provenance tests did not support this decision. The use of individual zones for each species and the use of line of latitude as boundaries to seed movement has created administrative problems for field staff. Therefore a review of the seed zones was undertaken with the aim of establishing a common set of seed zones for all species using definable or physical boundaries.

The revised zones (Dojack, 1990) were based on the previous criteria and:

--the intent of restricting seed movement to less than 1½° of latitude.

--the ecoregions delineated by Adams (1985). These are the broad zones used a pilot project to develop a forest site classification system for Manitoba.

--discussions with field staff. The aim was to realign the boundaries to improve their administration by field staff without compromising the intent of the zones.

A total of thirteen seed zones were established for the province (Figure 1). These zones represent a relatively minor realignment of Calverts 1973 zones.

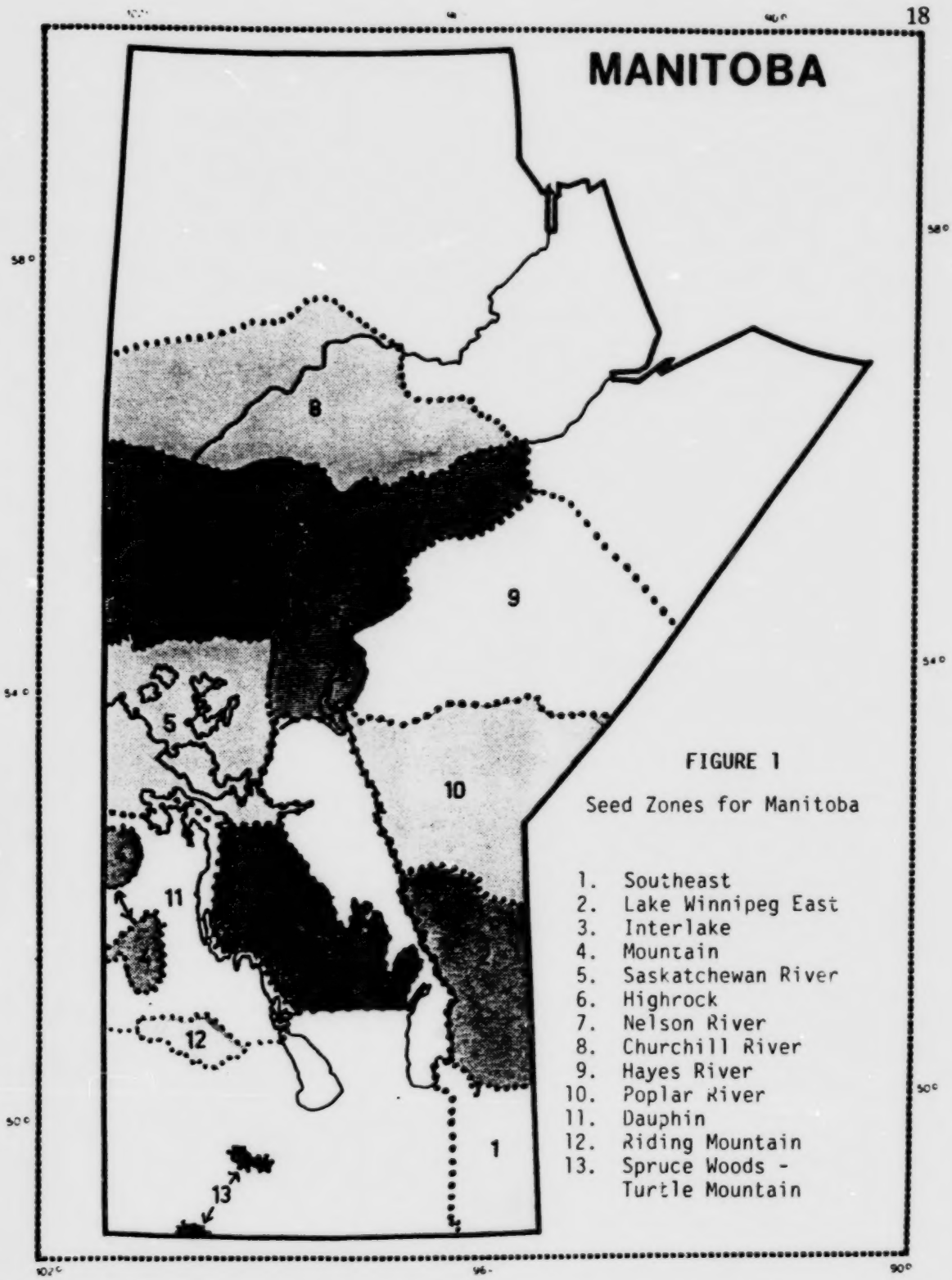



FIGURE 1

Seed Zones for Manitoba

1. Southeast
2. Lake Winnipeg East
3. Interlake
4. Mountain
5. Saskatchewan River
6. Highrock
7. Nelson River
8. Churchill River
9. Hayes River
10. Poplar River
11. Dauphin
12. Riding Mountain
13. Spruce Woods - Turtle Mountain

The following guidelines apply to seed movement within Manitoba:

1. The seed requirements for the renewal program of the various Management Units are to be met from seed collections within the applicable seed zones.

2. Transfer of seed outside of the seed zones must be approved by the Chief of Silviculture, Manitoba Forestry Branch.

3. It is recommended that in the Lake Winnipeg East seed zone the collection and movement of seed be kept separate between north and south of the Bloodvein River. However, in the event of a short-term seed or planting stock shortfalls transfer between the subzones is permitted.

4. It is also recommended that in the Mountain seed zone the collection and movement of seed be kept separate between the Duck and Porcupine Mountains. However, in the event of short-term seed or planting stock shortfalls transfer between subzones is permitted. Seed collections should be from the mid to upper slopes versus the lower elevations at the edges of the Provincial Forests to minimize elevation differences.

5. Red pine collections will also utilize the 13 seed zones.

## ESTABLISHMENT OF BREEDING ZONES

The term breeding zones refers to the geographic area within which plus trees are selected and interbred to produce genetically improved planting stock. Valid breeding zones are essential. If seed orchards are composed of trees from significantly different environments, the seed produced could be less hardy which would reduce the gains achieved.

At present specific information on the genetic variation of populations within Manitoba is not available. Previous studies have shown that the general pattern of genetic variation for black spruce (Morgenstern and Fowler, 1969), white spruce (Neinstaedt and Teich, 1971) and jack pine (Yeatman and Teich, 1969) is clinal. This continuous pattern of variation follows a geographic gradient (latitude and altitude) which is related to changes in photoperiod and temperature. White spruce has also demonstrated ecotypic, or discontinuous, variation often related to limestone deposits and subsequent pH levels (Teich and Holst, 1974). As mentioned previously, these general patterns of genetic variation were considered by Calvert (1973) in the formation of the initial seed zones. The seed zones chosen represent a safe, conservative approach which is recommended due to the lack of information on trends in Manitoba. It has been stated that the breeding zones need not be as conservative in order to amalgamate programs and reduce costs.

However, after discussing the differences that exist between the various zones with the local management foresters it was decided to keep the initial breeding zones similar to the realigned seed zones with the following exceptions:

-- the black spruce tree improvement program will be restricted to the 7 breeding zones with active renewal programs. The Swan-Pelican Provincial Forest is included as a part of the Interlake breeding zones. There is some uncertainty about the need to separate the Highrock and Nelson River breeding zones. Although the two zones are similar in latitude, there are noticeable differences in climate and physiography. From an economic standpoint establishing two separate seed orchard programs will be almost double the cost of a combined program. As a compromise it is recommended that selections from the two zones be combined in the family test and be kept separate in the seed orchard. Two family test plantations will be established in each zone.

-- the white spruce tree improvement programs will be restricted to the 3 breeding zones with renewal programs large enough to economically justify a tree improvement program. In the Bisset breeding zone, Management Unit 23 is amalgamated with the area south of the Bloodvein River in order to increase the cost effectiveness of one large program versus two small programs. Two family tests will be established in each of the two areas in order to determine the significance of the physiographic differences between the areas.

-- the jack pine breeding zones are based on the breeding districts initially established by Forestry Canada (Klein, 1982).

## TREE IMPROVEMENT STRATEGY

The tree improvement strategy for each species is based on:

- silvics (i.e. age of flowering, seed retention, even vs uneven aged, etc.)
- ability to be propagated vegetatively (grafting and/or rooted cuttings)
- heritability values for the economically important traits and potential for improvement
- pattern and level of genetic variation
- seed requirements.

The last factor, seed requirements, affects the cost efficiency of the tree improvement program. As previously described, many of the costs associated with an intensive seed orchard program are fixed. When these costs are applied against a small planting program they often provide insufficient returns to economically justify the program. Based on these benefit : cost considerations, and existing constraints in funding and staffing, it is recommended that intensive seed orchard programs with family tests only be established in breeding zones with an annual planting program of at least 1.5 million seedlings. However, a number of Manitoba's breeding zones have forecasted planting programs below the 1.5 million mark. Therefore the strategy for each species will detail a lower cost program for zones with planting programs above 0.5 million seedlings and a seed orchard-family test program for zones above 1.5 million seedlings. Programs below the 0.5 million seedling mark will utilize seed collection areas (SCAs). SCAs are recommended for red pine due to the small planting program and the lower level of genetic variation within the species.

The seed orchard requirements for the various breeding zones are shown in Table 1. The size requirements are based on long term planting forecasts, predicted seed : seedling ratios, and estimated seed production from the orchards. The figures used in these calculations are included in the Appendix.

**TABLE 1**

Long Term Planting Forecasts[1] and Seed Orchard Requirements by Breeding Zone

| Species | Breeding Zone | Planting Forecast (MMs Trees) | Seed Orchard Requirements (ha) | Existing Seed Orchards |
|---|---|---|---|---|
| Black Spruce | Southeast | 1.3 | 5.3* | |
| | L. Winnipeg East | 2.3 | 7.6 | 7.5 ha |
| | Interlake | 1.0 | 4.0* | |
| | Mountain | 1.0 | 4.0* | |
| | Saskatchewan River | 2.2 | 7.3 | |
| | Highrock | 1.5 | combined orchard | |
| | Nelson River | 1.5 | for 10.0 | |
| | Total | 10.8 | 38.2 | |
| White Spruce | Bisset | 1.0 | 2.6** | |
| | Mountain | 1.5 | 3.9 | |
| | Saskatchewan River | 1.5 | 3.9** | |
| | Remainder of Province | 1.2 | SCAs | |
| | Total | 5.2 | 10.4 | |
| Jack Pine | Eastern | 3.2 | 10.0 | 6.0 ha |
| | Central Mountain | 0.5 | 1.0* | |
| | Interlake | 0.5 | 1.0* | 4.0 ha |
| | Northern - Sask. R. | 2.0 | 4.0 | |
| | - Highrock | 1.0 | 2.0* | 4.0 ha |
| | - Nelson | 1.0 | 2.0* | |
| | Total | 8.2 | 20.0 | 14.0 ha |
| Red Pine | Southeast | 0.3 | SCAs | |
| PROVINCE TOTALS | | 24.5 | 68.6 | 21.5 |

[1]Regional/Industry Forecast of Annual Planting Levels in 15 Years
*Lower cost program - mass selection seed orchards
**Container orchard program recommended

## 1. BLACK SPRUCE

Black spruce is presently the most important species in Manitoba's reforestation program accounting for 50 percent of all planting stock produced. The long range planting forecasts indicate that black spruce will retain its importance, eventually increasing to an annual planting level of 10.8 million seedlings.

Black spruce exhibits a persistent and semi-serotinous cone habit, the ability to flower at less than 10 years of age and lower levels of heritability for growth rate. Based on these factors the approach recommended for black spruce involves:

1) Selection based primarily on the mean performance of open-pollinated families in test plantations, and

2) Seed orchards planted with seedlings rather than grafts in the first generation.

The strategy for improving black spruce depends on the forecasted regeneration program for the various breeding zones (Figure 2). A seed orchard program is warranted to meet the higher projected needs of the Lake Winnipeg East, Saskatchewan River, Highrock and Nelson River breeding zones. This approach, as illustrated in Figure 3, involves the selection of plus trees and the collection of seed and scion material from the individual trees. The seed is used to establish open-pollinated family test plantations and a seedling seed orchard. The seed orchard is rogued based on the family test results, thereby leaving only the genetically superior families to cross-pollinate. The scion material is grafted and planted in the provincial clone bank at Pineland Nursery. Controlled crosses of the best clones will eventually be conducted to establish a second generation population for further selection, breeding and improvement.

A lower cost program is recommended for the Southeast, Interlake, and Mountain breeding zones. This approach, as illustrated in Figure 4, involves the selection of plus trees and the collection of their seed to establish mass selection seed orchards. The mass selection orchards are planted at close spacing and are selectively thinned based on evaluations at the orchard site, leaving only the best trees to cross-pollinate. These orchards serve the dual purpose of evaluating individuals and producing seed. In combining these purposes it is recognized that although the costs are lower the results are less accurate and the gains may be lower.

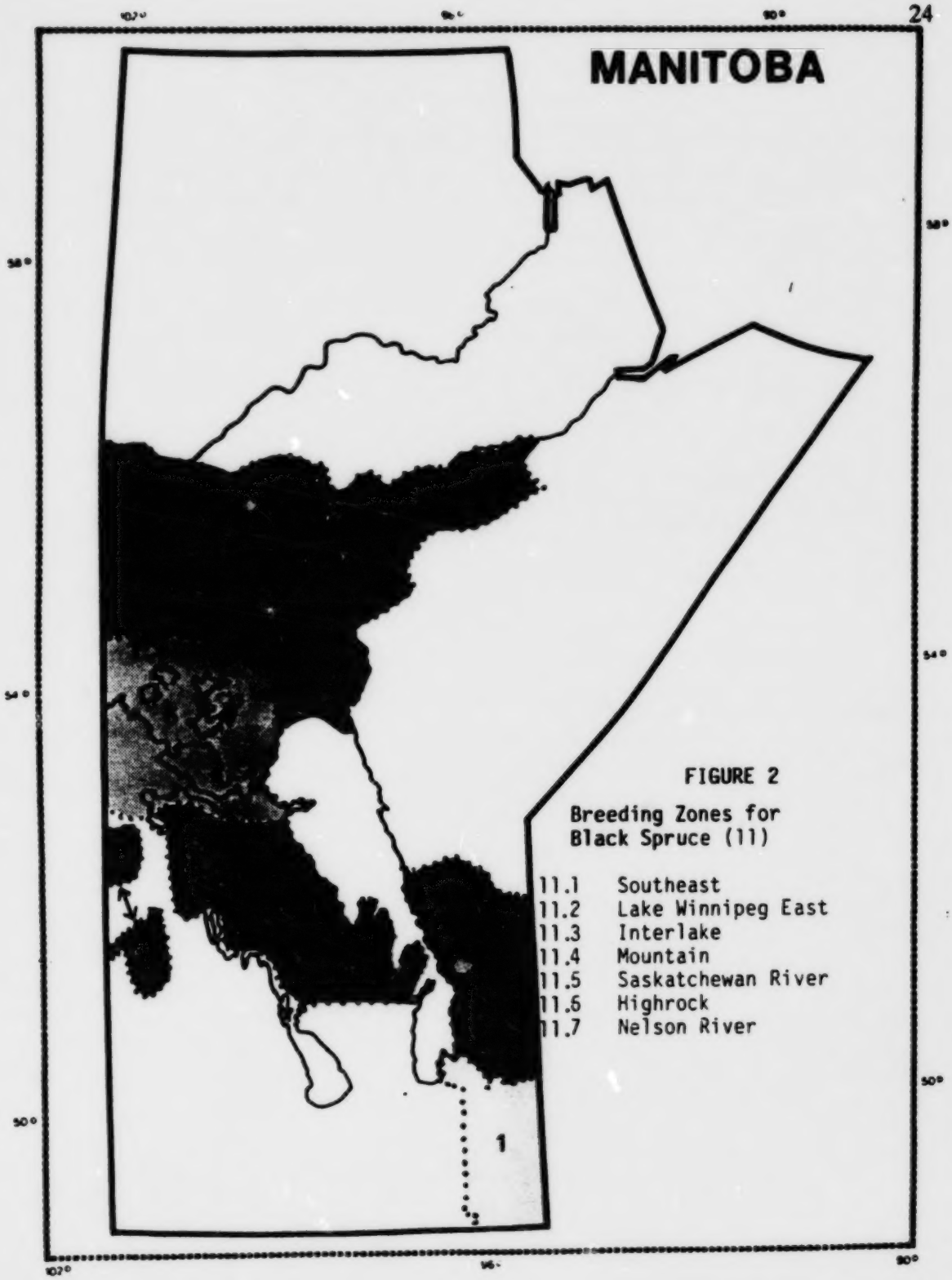



FIGURE 2

Breeding Zones for
Black Spruce (11)

| | |
|---|---|
| 11.1 | Southeast |
| 11.2 | Lake Winnipeg East |
| 11.3 | Interlake |
| 11.4 | Mountain |
| 11.5 | Saskatchewan River |
| 11.6 | Highrock |
| 11.7 | Nelson River |

Figure 3. Black Spruce Seedling Seed Orchard Program

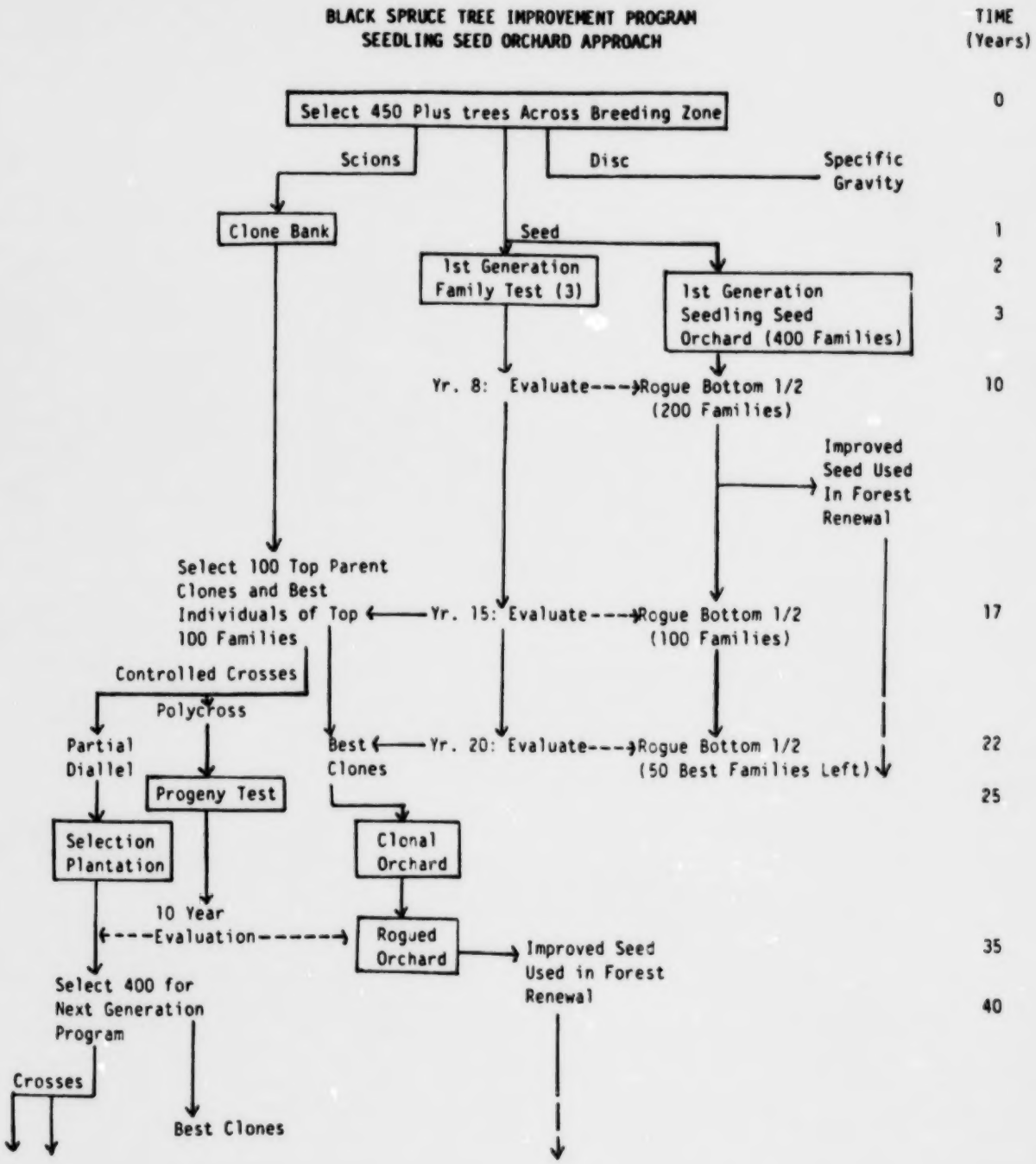
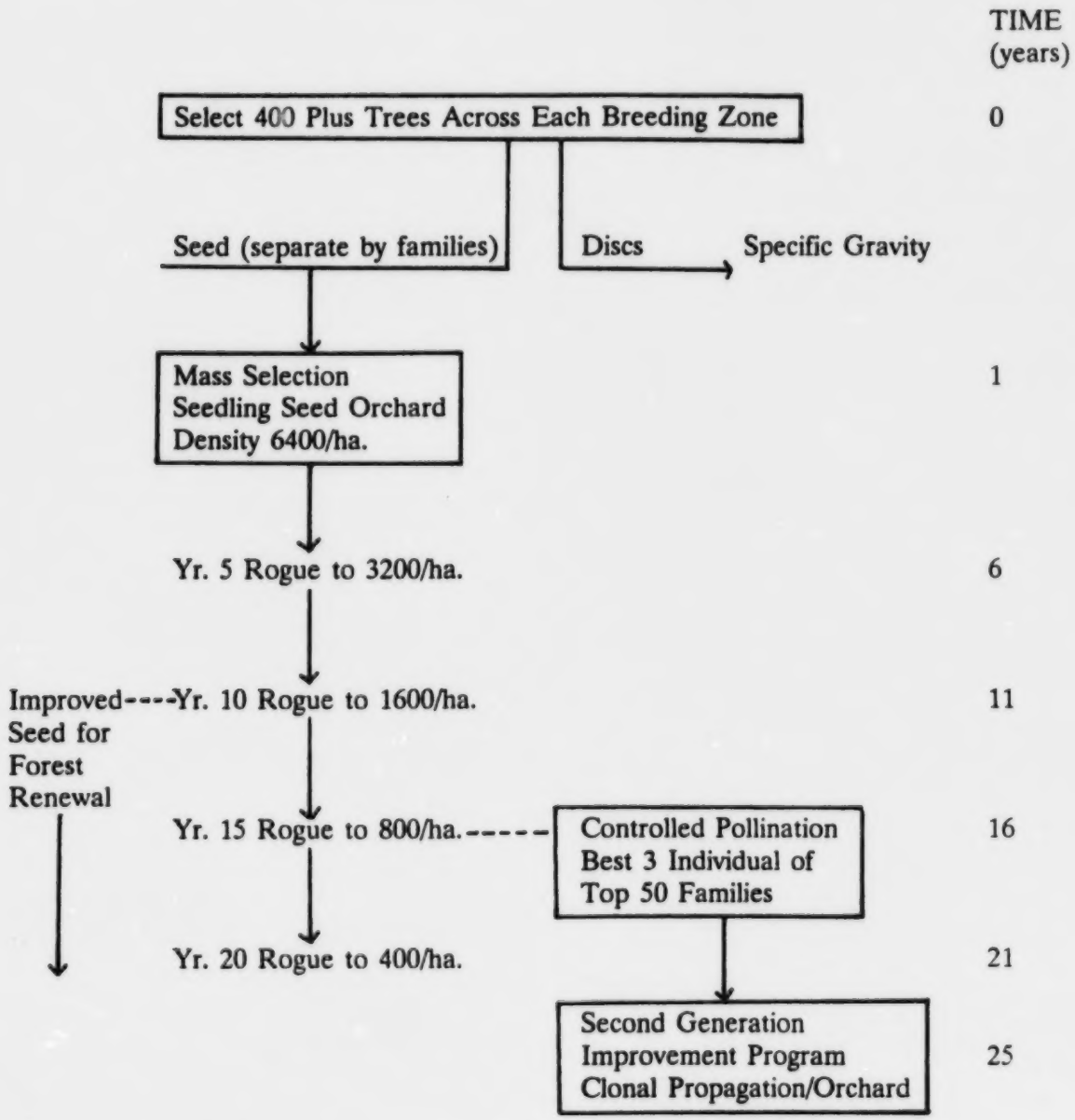


**Figure 4.** Black Spruce Mass Selection Orchard - Lower Cost Program

**BLACK SPRUCE TREE IMPROVEMENT PROGRAM**
**MASS SELECTION SEED ORCHARD APPROACH**



Plus Tree Selection Guidelines

The objective is to obtain a wide sample of populations throughout each breeding zone to ensure that the program is built on a broad genetic base. Candidate stands for selection are preferably 61-80 years old, a minimum of 10 hectares in size, 70 percent black spruce composition, 70 percent stocked and growing on productive sites. Candidate stands are identified based on field staff knowledge and forest resource inventory information (Stand Type: 13-1-3-3; 14-1-3-3; 53-1-3-3).

Once the candidate stands have been identified the decision is made to sample them using a ground crew or helicopter crew based on the proximity of access. The individual plus trees are selected using a low intensity (1/100 - 1/300) ocular comparison approach. Trees are rapidly assessed based on the following selection criteria:

| RANK | TRAIT | SELECTION |
|---|---|---|
| 1. | Stem Form | Straight, with no crooks or forks |
| 2. | Growth | Tree must be dominant, above average volume |
| 3. | Disease Resistance | No indication of damage |

Other traits which are considered but are ranked low, due to their being highly influenced by spacing, are crown shape and branch diametre. Branch angle is also ranked low due to the low level of variability and need for improvement. Growth is ranked lower when selecting plus trees, due to its lower level of heritability, but it is the highest ranked trait in the family tests.

A minimum of 400 plus trees are to be selected for the lower cost programs and 450 plus trees for the seed orchard programs. At least one-third of these selections are to be from ground crews with the remainder from aerial collections. Up to ten selections per zone from outside of the breeding zone may be included in the family tests. Including these trees will assist in determining seed zone boundaries and seed transfer guidelines.

Discs are to be cut from all ground selections at breast height in order to determine the parent tree's specific gravity. In addition to these discs, cones will be collected from each tree, and in the seed orchard program scions will also be collected. Plus tree selections must be separated by a distance of at least 100 metres to avoid selecting related trees.

Mass Selection Seed Orchard Guidelines

Mass selection orchards serve dual purposes of testing the seed from the initial plus trees and producing improved seed from the best individuals. These orchards could be described as expensive seed production areas because they are plantations established using seed from plus trees and then rogued periodically until only the best trees are left to produce seed. Thus the mass selection orchard is rogued based on how the individual trees are performing on the orchard site, not on how the family has ranked in separate family tests.

A mass selection orchard site must be uniform, with well drained productive soils, isolated from surrounding pollen, close to a labour supply and not located in a frost pocket. The orchard is planted at a very tight spacing of 1 metre by 1 metre and rogued before the trees complete with each other, every three to five years. Measurements and data analysis are not used to rogue the orchard. Trees are rogued strictly on an ocular comparison of two neighbouring trees with the poorest 50% removed with each roguing.

An example of a mass selection orchards layout is included in Appendix 2. The design of the orchard is as follows:

--Seed from 400 plus trees will be kept separate so that the seedlings can be grown labelled and eventually mapped by original plus tree number. Bulking the seed is not recommended as the loss of identity may result in potential inbreeding, especially when establishing the second generation program.

--100 seedlings from separate families are planted randomly, spaced at 1 metre by 1 metre within a square plot with a 3.5 metre access route left around each plot (6400 tree/hectare).

--Two - two hectare orchards will be established for each program to enable evaluating on two sites and as a safeguard against fire losses.

The evaluation of individuals in a mass selection orchards is less accurate than in family tests as there is more environmental variability due to uneven spacing after roguing. As a result, less genetic gain is expected than with the intensive program. In addition, because fertilizers can not be used to enhance growth and flowering, seed production will be lower than intensively managed orchards. However, the cost of establishing and managing the mass selection orchard program is less than one-third the cost of the intensive family test-seed orchard program. This approach is also significantly less expensive than the family test-rooted cuttings approach which was described in the initial draft of this strategy.

Open-Pollinated Family Test Guidelines

The seed collected from an individual plus tree is considered an open-pollinated family. The purpose of the family test is to rank the genetic worth of each of the 450 families. As previously described, the ranking of families for low heritability traits, like growth rate, is most efficiently conducted on uniform test sites where genetic influences can be accurately identified. To ensure uniformity, necessary steps must be taken during stock production, preparation of the planting sites and subsequent maintenance of the tests.

The family tests will be established using a single tree plot design. In this design one tree from each of the 450 families is planted in each replication. A total of 60 family members will be planted on at least 3 test sites and assessed in order to rank the mean value of the family. Single tree plots are recommended instead of row plots due to their increased statistical efficiency in ranking family means. This is a higher priority than selecting the best individuals within families, which row plots are more efficient at identifying. To achieve both objectives would require testing twice as many seedlings, the cost of which was prohibitive. Although 60 replications per family is lower than some tree improvement programs it should be statistically sufficient if the test sites are uniform and have high survival rates.

To meet the objective of higher survival rates, it was recommended that tree improvement seedlings be grown in larger (336 cc) containers under high pressure sodium lights. The black spruce tree improvement crops are grown to the following average dimensions: height 23.5 cm; calliper 3.0 mm; total oven dry weight 2.8 gm; shoot/root ratio 5.3:1 (Figure 5). Trays are rotated within the greenhouse three times during their growth period to minimize the impact of variation within the greenhouse.

**Figure 5.** Sorting family test crop after 21 weeks in the greenhouse, including 3 weeks of hardening off.

The stock is approximately 50% more expensive to produce (i.e. $625/m to grow, label, sort and ship) than other province's tree improvement crops. However it was decided that if survival rates could be increased, smaller tests could be used which in turn would reduce the overall production, labelling, planting, mapping and measurement costs. The first family tests established using this approach had second year survival rates of 97% even though the trees were planted during the 1988 drought. It is also hoped that using stock with larger caliper and higher root regeneration potential will lessen planting shock, improve crop response, reduce the impact of initial grass competition and thereby increase the validity of early assessments.

Family test sites are intensively site prepared by root raking, discing and ideally VISION is applied in August prior to planting. The increased cost (e.g. $1,100 - $1,500/ha) of intensively preparing family test sites will be slightly offset by lower staking and planting costs. However, the main reason for recommending intensive cultivation of test sites is that it has been shown to increase the survival, growth and expression of genetic differences (Kiss, 1981; Klein pers. comm. 1987). An example of one of the black spruce family test sites is shown in Figure 6.

It is inevitable that the number of families available for planting will be reduced due to poor germination. These families will be replaced with a general collection seedlot in order to assess how the mean of the selected families compares to the mean of a general collection and thereby determine the actual genetic gain. As previously indicated, families from other breeding zones will also be included to test the validity of the breeding zone boundaries.

An illustration of the layout of a family test plantation is included in Appendix 2. The statistical description of the experimental design is a Randomized Complete Block. Families will not be divided into breeding groups, as recommended in the initial draft, due to the increased cost and complexity of test layout and the general consensus of opinion from tree improvement specialists that this practice is not essential in the first generation programs.

In the seed orchard programs the family tests plantations will typically be planted one year before seed orchard establishment. This will enable tests to develop for a longer term and thus provide more reliable data before crown competition within the orchard necessitates roguing. Therefore the recommended test measurement schedule, using a 1988 spring plant as an example would be:

Spring 1989 (1 year old): survival and on site refill
Fall 1995 (8 years old): survival and height
Fall 2002 (15 years old): survival, height, diametre, stem form
Fall 2007 (20 years old): survival, height, diametre, stem form, specific gravity
(30 and 40 years old if required): height, diametre, stem form, specific gravity

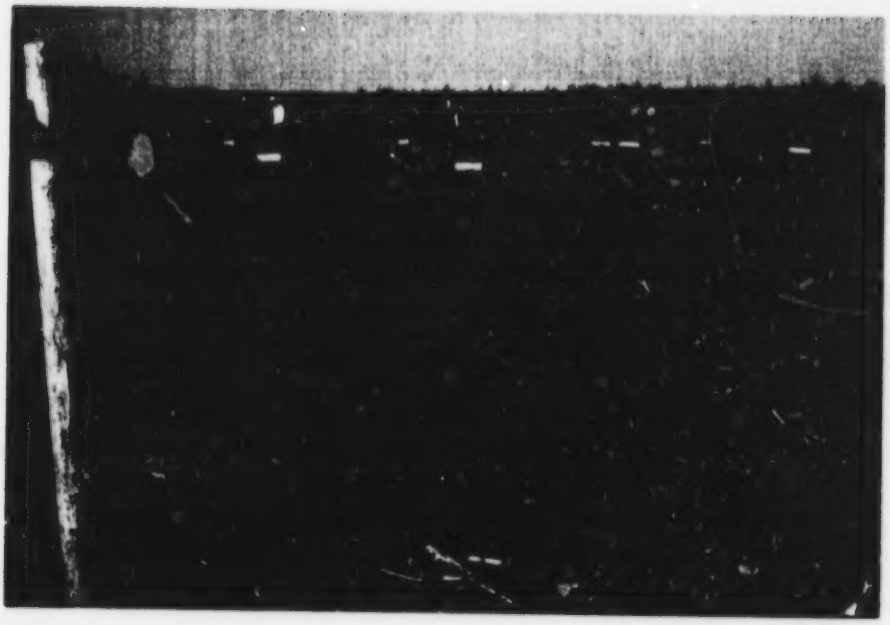


**Figure 6.** LaBroquerie black spruce family test site (Zone 11.1)

**Figure 7.** Brightstone black spruce seedling seed orchard site (zone 11.2), Abitibi-Price; Manitoba Forestry Branch co-operative program.

Survival and height measurements may be taken at 3 and 5 years, but this data will not be analyzed for the purpose of roguing the orchard.

Seedling Seed Orchard Guidelines

The seedling seed orchard is a plantation of the open-pollinated families using seed from the original plus trees. It is established and managed to produce abundant seed crops in a short time period. Substantial investments will be made in these orchards and therefore site selection is critical to ensure abundant seed production. The key factors to consider in site selection are a well-drained productive soil, good air drainage to prevent frost pockets, isolation from surrounding pollen, proximity to labour, security and ideally a warm south facing slope with water available ( Faulkner, 1975; Coles, 1980). The first generation orchards will ideally be established on sandy-loam sites with measures taken during site preparation to minimize the removal of the humus layer (Figure 7). The intent is to not establish a permanent irrigation system. However, a temporary irrigation system for the first-two years of establishment will be considered.

The orchards will be intensively managed to promote abundant seed production. Sites will be intensively cultivated prior to establishment with competing vegetation controlled and fertilizers applied to increase tree growth and flower production. In addition, the removal of the poorer families based on the family test results will follow a roguing schedule which ensures development of large crowns.

Seed production in the orchards is expected to commence at 8 years and rapidly increase as more of the families begin to flower. The individual seed orchard size requirements are indicated in Table 1. The figures used to calculate the seed orchard requirements are given in Appendix 1.

The design of the black spruce seedling seed orchards will be as follows:

--it is expected that the 450 families will be reduced to 400 families due to insufficient seed and poor germination. However, the orchard design will accommodate as many families as possible.

--one member of each family is randomly planted within a block. Trees are spaced at 1 metre within rows and 3 metres between rows. An example of the seed orchard layout is included in the Appendix.

--initial planting density is 3333 trees per hectares with a final spacing of 400 trees per hectare at 20 years.

The close initial spacing is required to facilitate a high roguing intensity in the first generation. Black spruce's relatively narrow crown form, and the establishment of the family test one year before the orchard, should enable a sufficient test period prior to roguing the orchard. Planting rows may be band sprayed the fall prior to planting to reduce competition within the rows. Competition between rows will be controlled by mowing or periodic ground applications of herbicides.

Fifty percent of the trees will be removed with each roguing. The roguing will be conducted as follows:

--trees from families ranked in the top 25% are retained
--trees from families ranked in the bottom 25% are removed
--trees from families ranked between the top and bottom groups will be retained or removed based on a judgement decision which considers spacing, family rank and the performance of the individual family member.

Clone Bank - Advanced Generation Breeding Program

Scion material from the original plus trees used in the intensive orchard program will be grafted and planted in the Provincial clone bank at Pineland Nursery. The clone bank is established to enable crossing the best of the original plus trees based on the family test results. These controlled crosses will produce the pedigreed seed for the establishment of the next generation selection and test population. This will enable the next cycle of testing, evaluation and production, and result in further increases in genetic gain. The clone bank and the best individuals in the family test will also supply the scions for establishing a second generation clonal orchard.

There is a great deal of disagreement amongst tree improvement specialists regarding whether or not establishing a clone bank of the original plus trees is economically justified for black spruce in the first generation. The high cost of grafting (e.g. $15/graft) and the fact that only one-quarter of the clones will be used makes postponing the grafting until the family tests are evaluated, and then grafting the best individuals of the best families in the test, appear more economical. However, if there are differences in growth between test sites, and thus significant genotype environment interactions, and if single tree plots are used it is more difficult to accurately identify the best family members. Based on these concerns and the fact that using the original selections should result in higher gains, it was decided that scions from the original plus trees would be used to establish the clone bank.

The breeding program will commence following the 15 year evaluation of the family test. Crosses will be made using the original parent clones in the clone bank and in some cases using the best family members from the family test plantations. The controlled pollination program follows the approach recommended for black spruce in the Maritimes (Fowler, 1986) A polycross is used to establish a progeny test to evaluate the clonal orchard and a partial diallel mating design is used to establish a selection plantation for advanced generation improvement.

## 2. WHITE SPRUCE

White spruce presently accounts for 25% of all planting stock produced. The long range planting forecasts indicate that the annual planting level will increase to 5.2 million seedlings.

White spruce is best suited to the establishment of clonal seed orchards. This is primarily due to the fact that seedlings are not sexually mature until approximately 20 years of age and optimal production may take 40 years. However, grafted scions maintain the sexual maturity of the original plus tree they were collected from.

Based on the expected planting programs (Table 1), the cost of a white spruce tree improvement program is economically justified in only three breeding zones. A seed orchard program is recommended for the Mountain, Saskatchewan River and Bisset breeding zones (Figure 8). The seed requirement for the other zones should be met from seed collection areas.

The clonal seed orchard program involves the selection of 380 plus trees and the collection of seed and scion material from the individual trees (Figure 9). The seed is used to establish four open-pollinated progeny test plantations. The scion material is grafted to establish a clonal seed orchard. The seed orchard is rogued based on the progeny test results thereby leaving only the genetically superior clones to cross-pollinate. Controlled crosses of the best clones will eventually be conducted to establish a second generation population for further selection, breeding and improvement. The white spruce tree improvement program for the Mountain breeding zone followed the clonal seed orchard approach. However, the cost of this program was higher than anticipated resulting in the need to review other methods for improving white spruce in the other breeding zones.

Another option for producing genetically improved white spruce seed is the use of container orchards. This approach involves the selection of 175 plus trees and the collection of seed and scion material from the individual plus trees (Figure 10). The seed is used to establish four open-pollinated progeny test plantations. The scion material is grafted to establish a clonal seed orchard which is grown in pots within plastic covered houses. The potted stock is expected to produce untested but high quality seed five years after grafting. After analyzing the progeny test's 8th year measurements, the best 100 clones will be control-pollinated to produce seed for the advanced generation breeding program. Genetically superior seed will be produced using the best 50 clones which will be retained with the container orchard. Three grafts from each clone will be maintained in a soil based clone bank to enable re-introducing clones if rankings change in subsequent family test measurements.

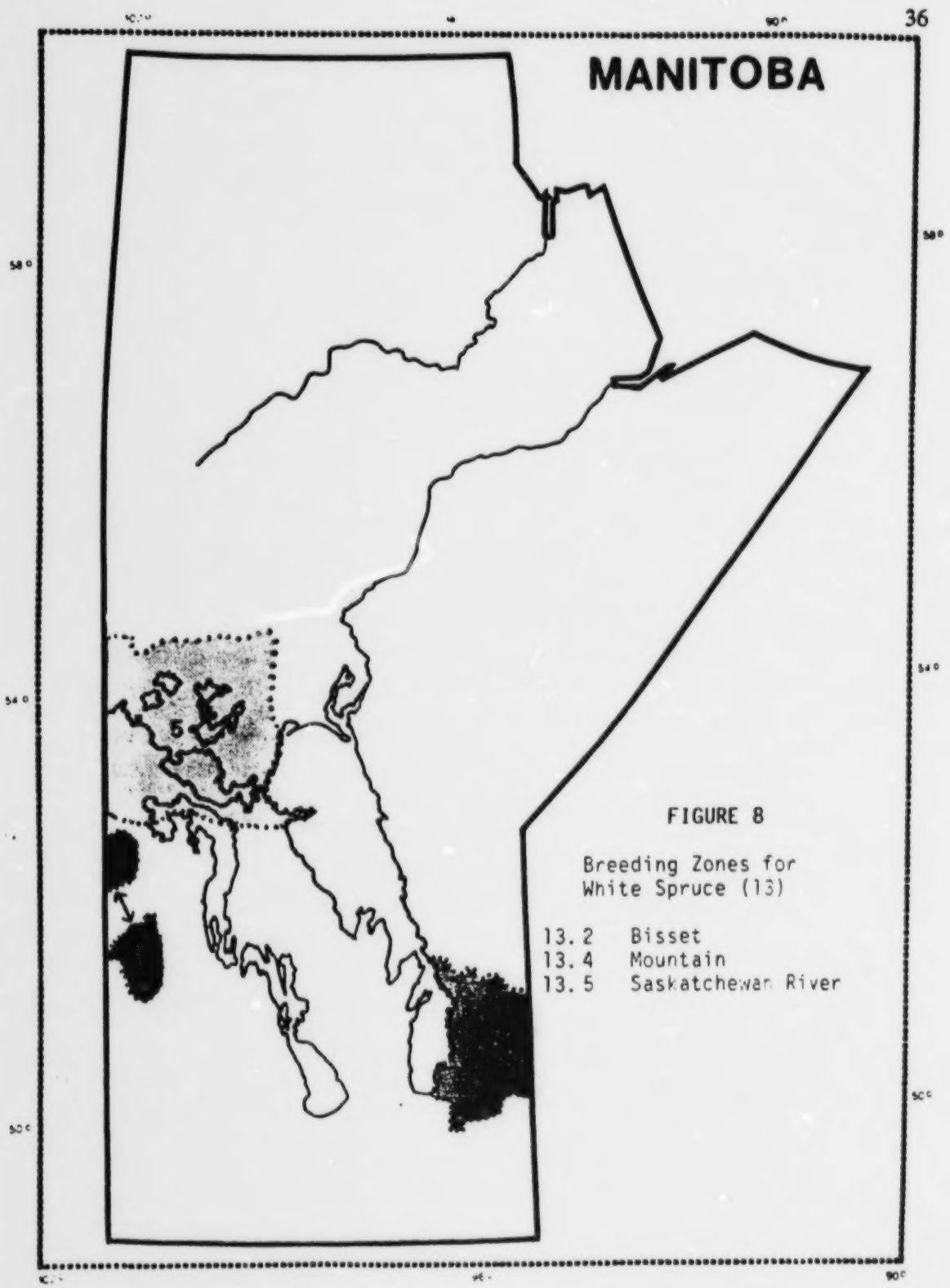



FIGURE 8

Breeding Zones for
White Spruce (13)

13.2 Bisset
13.4 Mountain
13.5 Saskatchewan River

**Figure 9.** White Spruce Clonal Seed Orchard Program



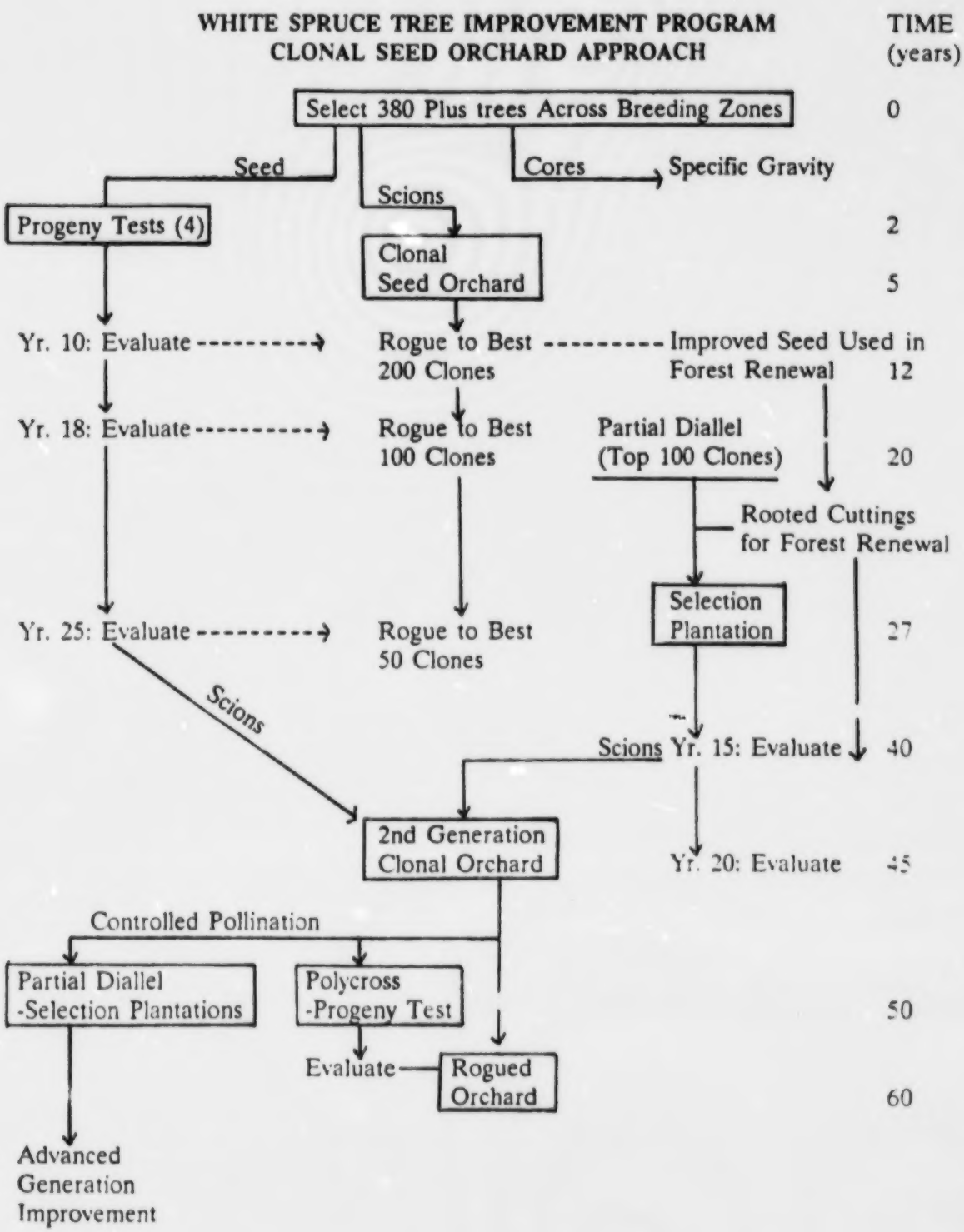
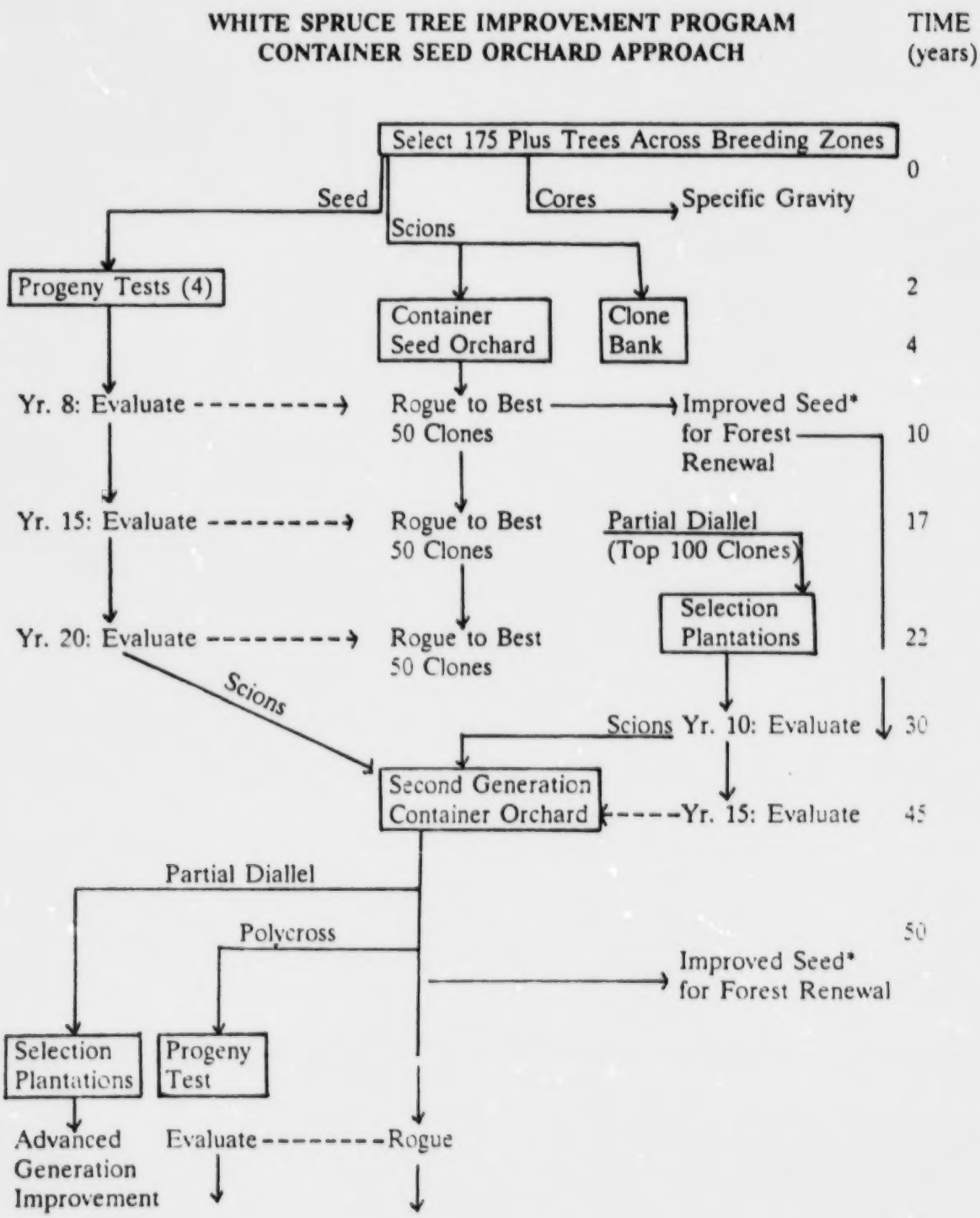


**Figure 10.** White Spruce Container Seed Orchard Program






*Planting stock may also be produced by vegetative propagation.

The cost savings with the container orchard approach results from using a lower number of plus trees which are selected more intensively, grafting 30% fewer scions, and lower establishment costs for the orchard. This approach is recommended for the Saskatchewan River and Bisset breeding zones.

Plus Tree Selection Guidelines

The objective is to ensure that the program is built on a broad genetic base by sampling populations throughout each breeding zone. Candidate stands for selection are preferably 61-80 years old, a minimum of 2 hectares in size, 50% white spruce composition, over 60% stocked and growing on productive sites. Candidate stands are identified based on field staff knowledge, field inspections and forest inventory information (Stand Types: 10-1-3-3; 11-1-3-3; 50-1-3-3).

The rapid maturing and dispersal of seed requires ground crews to make three trips to initially select the plus trees (Figure 11), collect mature cones in August and collect dormant scions in January. The aerial selection crews complete the operation in two passes. The first trip in August is to select the tree, collect cones, flag the top of the tree, and mark its location on an aerial photograph (Figure 12). The second trip in January is to collect dormant scions. The aerial selection program is essential to enable sampling inaccessible populations within the narrow collection window.

The individual plus trees are selected using a low intensity (1/100 - 1/250) ocular comparison approach. Trees selected for container orchards will be selected more intensively as fewer trees are selected. Trees are rapidly assessed based on the following selection criteria:

| RANK | TRAIT | SELECTION CRITERIA |
|---|---|---|
| 1 | Stem Form | Straight with no crooks or multiple tops. A slight sweep or lean is acceptable. |
| 2 | Growth | Tree must be dominant/codominant with vigorous leader growth and good cone production. |
| 3 | Branch Angle | Within 20 degrees of horizontal is preferred, within 45 degrees of horizontal is acceptable. |
| 4 | Disease Resistance | No indication of damage. |

**Figure 11.** White Spruce plus tree selection - Ground Crews (Zone 13.4)

**Figure 12.** White Spruce plus tree selection - Aerial Crews (Zone 13.4)

Other traits which are considered but ranked low are crown shape, branch diametre and self pruning ability. Growth rate is ranked lower when selecting plus trees due to its lower level of heritability. However, it is the highest ranked trait in the progeny test where environmental variation is minimized. Specific gravity measurements will be recorded for all ground selections from a core, 12 mm in diametre, taken at breast height (Figure 13). This data will be used to determine juvenile-mature correlations at a later date.

**Figure 13.** Increment core (12 mm) taken from a white spruce plus tree for specific gravity measurements (Zone 13.4).

The clonal orchard program for the Mountain breeding zone (13.4) involved selecting 380 plus trees, 80 of which were selected by ground crews. The container orchard program involves selecting 175 plus trees, 100 of which are selected by ground crews. The decision to reduce the number of plus trees selected and increase the selection intensity was due to:

1) the high cost of selecting, grafting and testing 380 trees;
2) the less frequent occurrence of white spruce in the other breeding zones; and
3) the importance of improving stem quality traits, which are highly heritable, in white spruce.

It is imperative that all plus trees are selected in larger bluffs of white spruce, in good seed years and preferably within the 41-100 year age class. If seed is collected from overmature trees located in small isolated patches or in poor seed years, the seed may be inbred due to only a few of the surrounding trees being involved in the pollination and a higher likelihood that they are related. The use of inbred seed will not enable an accurate evaluation of the parent tree's genetic worth. In addition, the plus trees selected must be separated by a minimum of 500 metres to avoid the selection of relatives which could cause inbreeding problems within the orchards.

Open-Pollinated Progeny Test Guidelines

The seed collected from an individual plus tree, and used to evaluate the parent tree (clone), is considered its open-pollinated progeny. The purpose of the progeny test is to rank the genetic worth of each of the original plus trees. For low heritability traits like growth rate, evaluation is more efficient when conducted on uniform test sites where genetic influences can be accurately detected. Although a polycross test would provide a better estimate of each clones general combing ability, open-pollinated seed will be used for the first generation progeny tests. This decision was made as it would enable earlier test results and at a lower cost.

The progeny test will be established using a single-tree plot design where one seedling from each plus tree is planted in each replication. Sixty progeny from each plus tree will be planted and assessed to rank the original plus trees. The 60 progeny will be planted in 4 test plantations with 15 replications per site. The layout of the plantations will be similar to the approach used for black spruce.

White spruce seedlings often go into check following field planting. Planting shock should be reduced by selecting appropriate test sites, intensively cultivating the sites and using planting stock with high root regeneration potential (Figure 14).

It is essential that an adequate time period is allowed for seedling development prior to test evaluation. However, test evaluation must follow a schedule which enables roguing the clonal orchard prior to the crowns closing. Therefore, the progeny tests will be established two years before the orchard with test measurements planned at 10, 18 and 25 years. The tests will be fenced in areas where the potential for browsing damage is high (Figure 15).

Figure 14. White spruce progeny test seedling's root regeneration 20 days after planting (Zone 13.4).

Figure 15. Shortdale white spruce progeny test site (Zone 13.4).

Clonal Seed Orchard Guidelines

The clonal seed orchard is a plantation of grafted seedlings, using scions from the original plus trees. It is established and managed to produce abundant seed crops in a short time period. The appropriate selection of a clonal seed orchard site for white spruce is crucial. Selection criteria are similar to black spruce except good air drainage to prevent frost pockets is extremely important and a slightly siltier soil is preferred.

The investment in, and subsequent management of, clonal orchards is much higher. Sites must be intensively site prepared and fenced, and usually include the establishment of an irrigation system. The clonal orchard for the Mountain breeding zone (13.4) program will be established at the Birds Hill nursery site. The design of the white spruce clonal seed orchard will be as follows:

--it is expected that the 380 clones will be reduced to 300 due to insufficient seed for the progeny tests, loss of plus trees prior to scion collection and graft mortality. However, the orchard design will accommodate as many clones as possible.

--the surviving clones which are represented in the progeny tests will be planted in the orchard using a randomized complete block design with one ramet of each clone randomly planted within a block. Trees are spaced 2 metres within rows and 4 metres between rows at an initial density of 1250 trees per hectares.

The spacing for the clonal orchard enables a high roguing intensity in the first generation and long term access corridors. White spruce typically develops a relatively broad crown when open grown. Spacing in the orchard must be wide enough to encourage large crowns and increased flower production. To ensure adequate spacing in the orchards it is expected that roguing will be required as follows:

--8 years after establishment the best 200 clones are retained (833 trees/ha)

--16 years after establishment the best 100 clones are retained (416 trees/ha)

--23 years after establishment the best 50 clones are retained (208 trees/ha).

Cone production in the orchard should be significant within 8 years of establishment (Nienstaedt and Jeffers, 1970; McPherson et al. 1982). The size requirements for the seed orchards are given in Table 1.

Container Seed Orchard Guidelines

The container seed orchard will also be established with grafted seedlings, using scions from the plus trees. However, instead of being planted, the stock is maintained in large pots within plastic covered houses similar to cold frames.

The advantages of this approach over soil based orchards are:

--earlier more consistent and more abundant flowering. This is due to the fact that optimal flowering requires an early drought during the period of rapid shoot elongation followed by high temperatures during cone bud differentiation (Ross et al., 1985). If either of these treatments occurs at the wrong time they can inhibit flower production. This optimal timing rarely occurs in nature, thus accounting for cone crop periodicity, but can be easily created using indoor container orchards. This would enable consistent cone crops every two years.

--better protection of developing flowers, cones and seed from adverse climatic conditions, resulting in higher yields. Experience with container orchards in British Columbia has shown that 7 year old white spruce grafts can on average produce 3,000 seed per ramet biennially (Ross et al., 1985). This level of production is not expected from the grafts in the soil based orchard until they are 20 years old.

--higher selection and roguing intensities can be used based on the initial test results thus enabling higher initial gains. Soil based orchards are recommended to be rogued by 50%, based on each measurement of the progeny tests. A higher roguing intensity in soil based orchards is not recommended as changes in the clonal ranking are possible and once a clone is removed it would take 10-15 years before it could be re-introduced and developed to a point where it contributes to pollination. However, with potted stock their development can be accelerated enabling clones to be re-introduced with 5 years. This will enable higher selection intensities to be used without a major reduction in seed production if clones change ranking. Experience in British Columbia has shown that using the best 25% of the clones based on the initial measurement of progeny tests resulted in height and diametre gains of 10-15% and total volume gains of 30-40% (Kiss pers. comm. 1990). Intensively cultivated test sites were essential to the above results as crop development was enhanced and changes in ranking during subsequent measurements was minimized.

--breeding programs for subsequent generations can be initiated earlier and completed in a shorter time frame. The use of growth regulators and nitrogen fertilizers in conjunction with water stress and high temperature treatments in container orchards has been shown to enable the production of male and female flowers on all clones. Young soil based orchards typically have problems with few clones flowering and often at different times, which restricts any controlled crossing program.

--the cost of producing improved seed will be lower. Based on the British Columbia container orchard figures for white spruce (Ross et al., 1985), 1600 grafts could produce 2.4 mm seed per year, 7 years after grafting. It was estimated that this would require a 10m x 35m plastic-covered house with a propane heater and let-down sidewalls for natural ventilation, and a 350m$^2$ outdoor container yard each equipped with moveable pallets and automated drip irrigation systems, at a cost of $22,500 in 1985 Canadian dollars. The estimated cost of a 4 hectare soil based clonal orchard is $8,000 for site preparation, $10,000 for fencing and $25,000 for an irrigation system. Other savings include grafting 4375 versus 6250 scions at a saving of $19,000 and lower management costs due to the orchards being centralized in one location.

The container seed orchard program would be established as follows:

--175 plus trees are selected using a higher selection intensity ($^1/_{150}$ - $^1/_{300}$) and a higher proportion of ground selections (100 ground; 75 aerial).

--Seed from the plus trees is used to establish four open-pollinated progeny test plantations. The progeny test is evaluated at years 8, 15, and 20.

--25 scions from each plus tree are grafted for the container orchard. The 4375 grafts are expected to be reduced to 3500 grafts due to mortality.

--Grafted stock is maintained in pots, but operational flower induction treatments do not commence until the first evaluation of the progeny test (7 years after grafting). Following the evaluation the best 100 clones are crossed using a partial-diallel mating design to establish a selection plantation, upon which the 2nd generation program will be based.

--The best 50 clones, based on the progeny tests first evaluation, will be used for the operational production of improved seed for forest renewal. The expected production level would be 1.5 mm seed per year. At this time 1000 more grafts of the best 50 clones will be made to help boost seed production and eventually replace the older potted trees. Scion material for these grafts will be collected from the grafts planted in the soil-based clone bank.

--If there are any changes in clonal rankings, with the 2nd and 3rd evaluations of the progeny test, the new top clones will be added to the production population.

--If seed production is lower than anticipated, vegetative propagation may also be used to produce improved planting stock for forest renewal programs.

Advance Generation Breeding Program

Following the second evaluation of the progeny tests, a controlled pollination program using a partial diallel mating design will be initiated using the top 100 clones. These controlled crosses will produce the pedigreed seed for the establishment of the next generation's selection population. Scions from the best individuals within the selection plantation and the original open-pollinated progeny test will be grafted to establish the 2nd generation orchard.

The breeding program for the advanced generations will follow the approach recommended for white spruce in the Maritimes (Fowler, 1986). The selections from the first generation progeny test and selection plantation are used in controlled pollination programs to produce the second generation test and selection populations. The partial-diallel mating design enables each clone to be crossed with two or more other clones. The full-sib progenies which are produced will be used to establish the selection plantation for the next breeding population.

The polycross design involves pollinating selected trees with a common mix of pollen. It enables determining the general combining ability of the selected trees in the seed orchard. Only the clones with high general combining ability, as determined in the progeny test, will be left in the seed orchard.

## 3. JACK PINE

Jack pine presently accounts for 23% of all planting stock produce in Manitoba. However, if genetically improved planting stock were available, this level would increase to 33% or 8.2 million seedlings.

Jack pine is best suited to a seedling seed orchard approach due to its persistent and sertinous cone habit, ability to flower at an early age, slow crown development for grafted stock, and low heritability for growth rate. A clonal forestry program is presently not a feasible option for jack pine as this species has not been successfully propagated from rooted cuttings at an operational scale. However, clonal forestry would be particularly beneficial for a species like jack pine as the collection of cones from orchard trees will be labour intensive and expensive. Therefore this program will be highly emphasized in supportive research proposals.

The jack pine tree improvement program was established by Forestry Canada in co-operation with the Manitoba Forestry Branch. The program was initiated in two phases and will eventually meet all of the Provincial planting stock requirements. As a result this section will describe the program in place and future developments.

### Initial Breeding Program for Manitoba's Eastern and Mountain Areas

The first phase of the program was established in 1967 in the Eastern (Pineland-Bisset) and Central (Duck-Porcupine Mountains) Breeding Districts and is described in detail by Klein (1982). A total of 226 plus trees were selected across the Eastern District and 244 were selected throughout the Central District, one-half of which is located in Manitoba (Figure 16). The trees were selected based on ocular comparisons of stem form, branch angle and vigour. Cones and scions were collected and kept separate for each tree, identified by its plus tree number. Scion material was grafted and placed in a clone bank.

Seed from 216 of the trees was used to establish four open-pollinated family test plantations in each Breeding District. The Eastern District plantations were established in May, 1971 at a 1.8 metre x 1.8 metre spacing. The Central District plantations, two of which were in Manitoba, were established in May, 1976 at a 2.5 metre x 2.5 metre spacing. The trees were planted in row plots with four family members planted in a row, three replicates per plantation and four plantations per Breeding District. Therefore, a total of 48 seedlings of each family were planted in order to assess the families ranking. The statistical design of the tests is referred to as a cubic lattice design which is a form of an incomplete block design.

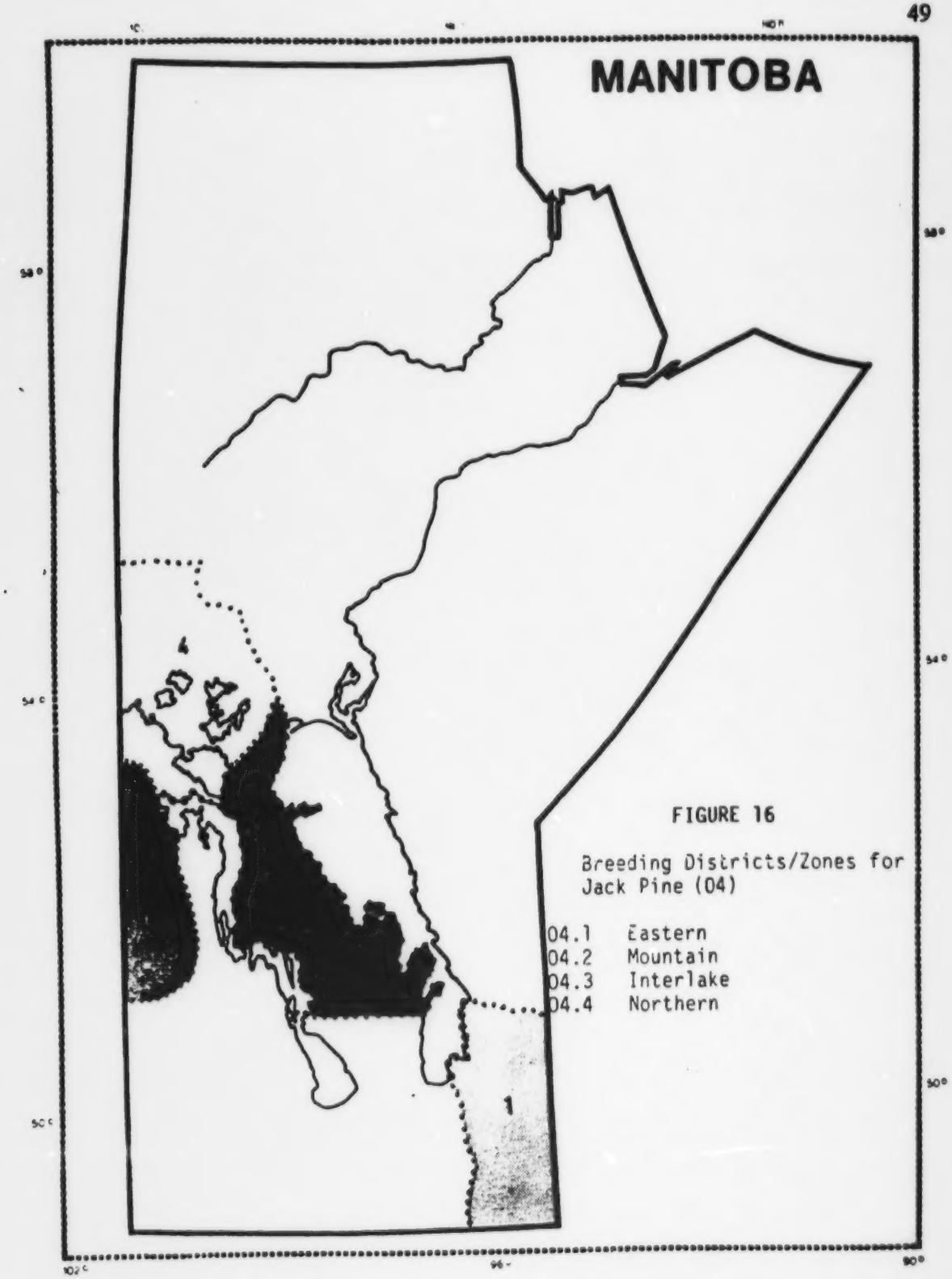



FIGURE 16

Breeding Districts/Zones for Jack Pine (04)

04.1 Eastern
04.2 Mountain
04.3 Interlake
04.4 Northern

The Eastern District family test plantations have been measured at 5, 10 and 15 years of age. Based on the 10-year measurements the 5 best family members of the 40 top ranked families were used in a controlled crossing program to produce 18-1st cousin progenies. These progenies were sown in January, 1988 and grown under high pressure sodium lights for six months prior to outplanting as a pedigreed seed orchard in August, 1988.

Initially 6 hectares were planted with the 18-1st cousin progenies in a permutated neighbourhood design. The trees are planted at a wide spacing (5 metre x 5 metre) because they will not be rogued. The orchard will eventually be expanded to 10 hectares using progeny from an additional 20 single-pair matings based on the 15-year measurements of the Eastern Breeding District family tests.

The second generation breeding program will commence following the analysis of the 20-year measurement of the Eastern Breeding District family tests. The second generation breeding population will be established from single-pair matings of approximately 240 parents based on the mating design developed by Forestry Canada. A short term polycross test to assist in identifying the 240 parents has been recommended (Klein, pers. comm., 1990). However, the current level of funding and resources prohibits including the polycross test. A second generation orchard will not be established as the existing pedigreed orchard will contain progeny from most of the selected parents. A flow chart of the Eastern Breeding District program is shown in Figure 17.

A separate study is being established to screen the 18-1st cousin, progenies and eventually the second generation families for western gall rust (Endocronartium harknessii) susceptibility (Anon., 1988). Families which possess and unacceptable degree of susceptibility will be removed from the pedigreed seed orchard at Oakbank (Figure 18).

The Central Breeding District program is being scaled down to a lower cost option due to the low planting stock forecast for the Duck and Porcupine Mountains. The most attractive options for this program are the production of rooted cuttings or the establishment of a container orchard based on the 10 year test data. However, further development of these procedures is required before they may be considered as operationally feasible options.

Figure 17. Jack Pine Orchard Program for Eastern Breeding District

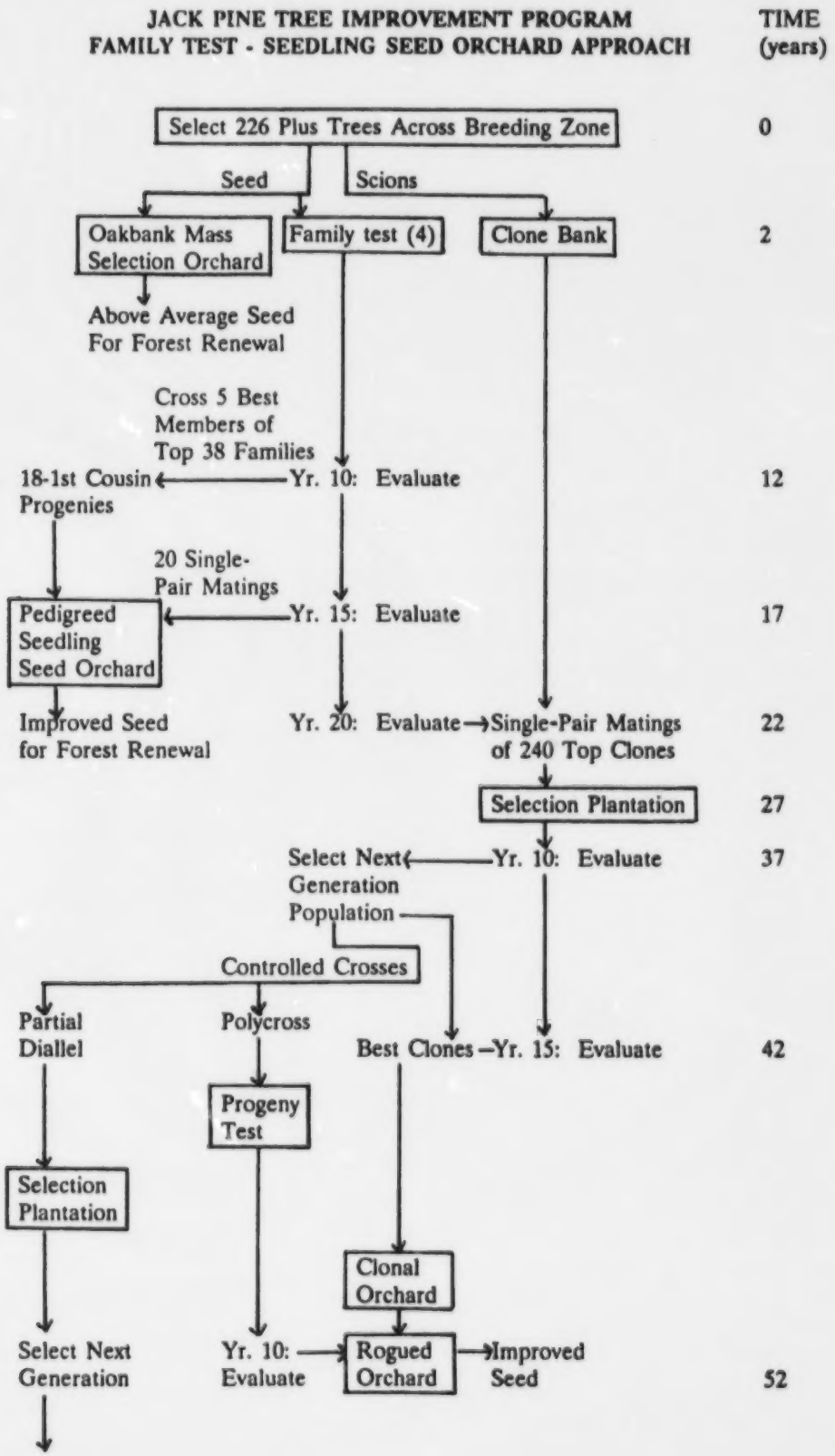


**Figure 18.** Oakbank pedigreed jack pine seedling seed orchard (Zone 04.1)

**Figure 19.** Root lake jack pine mass selection seedling seed orchard (Zone 04.4)

Recent Breeding Programs for Manitoba's Northern and Interlake Areas

In 1984 under the Canada-Manitoba Forest Renewal Agreement, jack pine tree improvement programs were initiated in the Northern and Interlake Breeding Districts (Figure 16). The relatively low planting levels in these areas resulted in a lower cost approach being utilized. The program involved selecting 10 plus trees in 32 source stands throughout each Breeding District. Cones were collected from the trees and bulked by stand. Seed was kept separate by stand and grown to establish mass selection seed orchards (Figure 19). A flow chart of the breeding program is shown in Figure 20.

In 1986, 2-2 hectare mass selection seed orchards were established in the Northern District and in 1987 a 4 hectare orchard was established in the Interlake District. The mass selection orchard is planted at close spacing and selectively thinned every 3 to 5 years leaving only the best trees to cross pollinate. The design of the orchard is as follows:

--The seed from the 320 plus trees is bulked by stand (10 trees/stand: 32 stands). The bulked seed from each of the 32 source stands is kept separate by stand.

--The seedlings are planted at 1 metre x 1 metre spacing within plots, with a 4 metre access row left around plots, as illustrated in the Appendix.

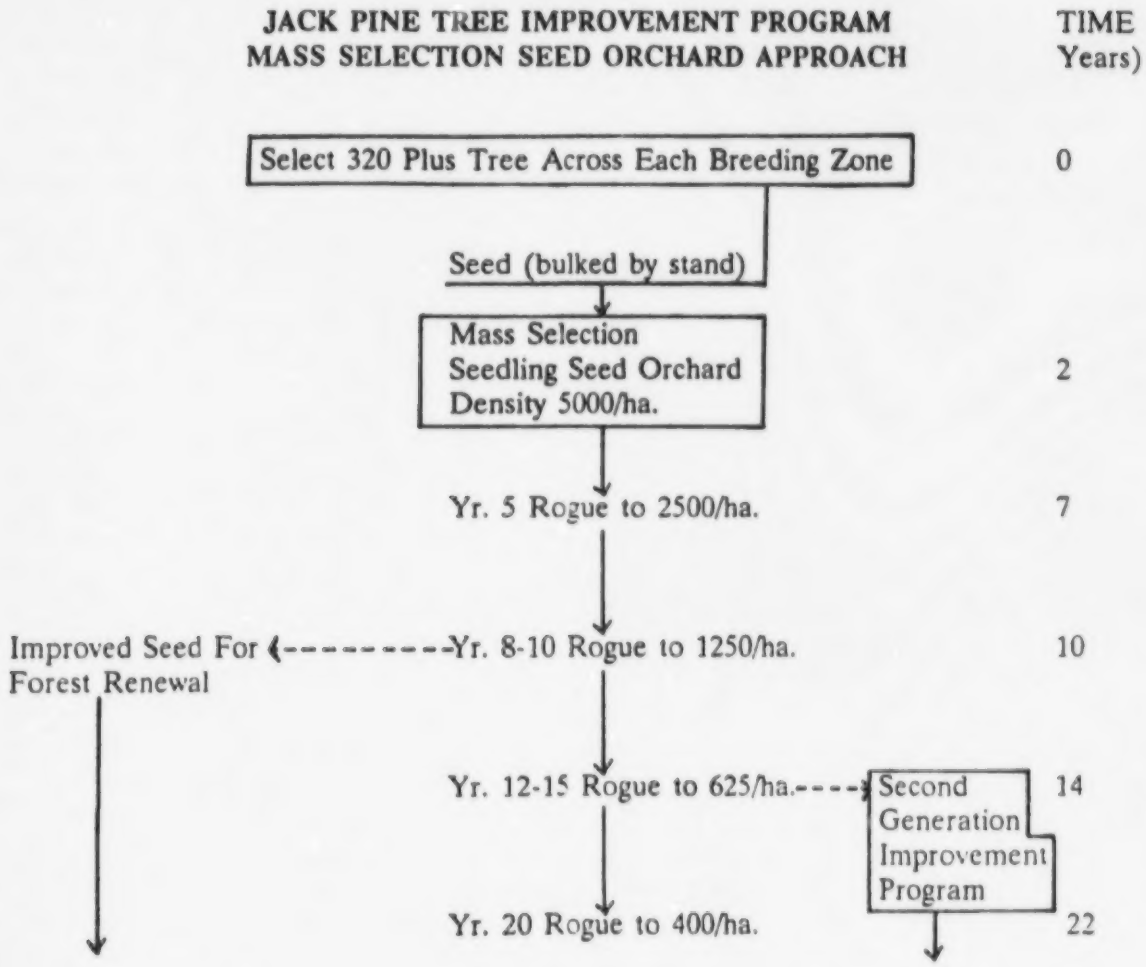
--Each replicate contains 32 plots, with each plot containing seedlings from only one source stand.

--The Northern District orchards contain 48 seedlings per plot with 6 replicates per site on two sites (48 x 32 x 6 x 2 = 18,342 seedlings in total).

--The Interlake District orchard contains 25 seedlings per plot with 25 replicates on the one site (25 x 32 x 25 x 1 = 20,000 seedlings in total).

The orchard is selectively thinned by 50% based on ocular comparisons of neighbours within each plot. Thinning is expected to occur every 3 to 5 years to a final density of 400 trees per hectare. This equates to leaving four trees per plot in the Northern orchards and two trees per plot in the Interlake orchard.

**Figure 20.** Jack Pine Mass Selection Orchard Program



## MANITOBA TREE IMPROVEMENT CO-OPERATIVE

Tree improvement programs necessitate long term commitments of funds and personnel. Across Canada the formation of tree improvement co-operatives between industry, government and often university agencies has enabled the pooling of expertise, personnel and funds. The sharing of knowledge, workload and costs amongst the agencies enables programs to be established at an accelerated pace with increased cost efficiency and commitment.

In recognition of the above facts initial discussions on the formation of tree improvement co-operatives, were held with Abitibi-Price Inc., Repap Manitoba Inc. (formerly Manfor Ltd.) and the Manitoba Forestry Branch in 1987. These discussions were timely as the first draft of the Tree Improvement Strategy was just being developed and no applied tree improvement programs had been initiated for black or white spruce. Following the discussions informal agreements were made and co-operative programs initiated between the Forestry Branch and both forest industry companies.

The success of other tree improvement co-operatives has not rested on the formation of binding legal obligations amongst the members. Prosperous co-operatives have been the result of the member's personal and financial commitment, open communication, realization that it their program and being provided sound direction by the program co-ordinator (Zobel, 1981). Therefore, instead of forming a legal agreement a Memorandum of Understanding was developed to describe the co-operatives purpose, structure and member responsibilities.

### PURPOSE OF THE CO-OPERATIVE

To increase the yield and quality of wood produced from plantations by co-operating in the implementation of operational tree improvement programs.

### ORGANIZATIONAL STRUCTURE

A) Steering Committee --Composed of the Chief of Silviculture, Industrial Representative, Regional Forester and Tree Improvement Specialist.

Term of Reference --Identifies long term planting projections and species priorities. Approves program direction and establishes implementation schedule. Identifies agency responsibilities and approves budget in accordance with workplan. Reviews Annual Report and meets when required.

B) Working Group --Composed of Industrial and Regional tree improvement representatives, Tree Improvement Specialist and Tree Improvement Technician.

Terms of Reference --Prepares annual workplan in accordance with the programs implementation schedule. Each agency budgets for its own workplan. Implements approved program ensuring that quality standards are met. Identifies problems and research needs to Steering Committee. Prepares an Annual Report for the Steering Committee.

Member Responsibilities

The distribution of workload for field operations is based on projected seed requirements and is reflected in the distribution of improved seed between Industry and the Forestry Branch. The improved seed from the orchards will be used to produce container stock or greenhouse transplants due to their more efficient use of seed. The production of bareroot stock will be of lower priority and improved seed will not be used for direct seeding programs. The distribution percentages for the improved seed may be changed from the original levels if both of the co-operators agree with the change.

All costs associated with stock production and grafting are covered by the Forestry Branch and not included in determining workload distributions. The responsibilities for the establishment and management of an orchard or test plantation are generally given to one agency. The budget estimates were used to distribute workloads and identify approximate financial commitments during the expensive establishment phase. In determining the budget estimates each activity has been assigned a unit cost. The distribution of improved seed is based on these costs and not the actual cost incurred by the co-operating agency. Therefore if the target is achieved at a lower cost, and the methods used are consistent with the direction provided in the Provincial Tree Improvement Strategy, the distribution percentages will not be changed.

Examples of the distribution of workload, costs and improved seed for two co-operative programs are given in the Appendix.

## IMPLEMENTATION SCHEDULE

The recommended implementation schedule for the tree improvement program (Table 2) was developed based on constraints in staffing and growing facilities. The implementation schedule and estimated funding requirements (Figure 21) are separated into three phases. The division into phases is to establish program priorities and assist the Forestry Branch in identifying the scale at which the program will be initiated based on the availability of funds. This review is crucial to ensure that once each project is initiated, funding will be sufficient during the costly establishment period. The levels shown in Figure 21 include the costs of implementing the operational program to the Silviculture Section, Industrial Co-operators, Regions and Pineland Nursery.

The division into phases is as follows:

Phase 1:
Continue existing programs (jack pine orchards and Southeast black spruce).
Initiate co-operative programs with Abitibi-Price and Repap for their priority species, black spruce, in their priority breeding zones.
Initiate white spruce program in the Mountain zone.

Phase 2:
Initiate co-operative family test and orchard programs for the second priority species and second priority zones.
Initiate support research (container orchards, rooted cuttings) for jack pine program.

Phase 3:
Initiate lower cost programs for lower priority programs.

If the program is implemented according to the schedule in Figure 21, progress will be as follows:

A) Within 5 years (1990-1995)

--All planting stock will be grown from source identified collections (SCAs) resulting in improved plantation performance and tree form.

--The plus tree selection program for all Breeding Zones will be completed.

--All first generation family tests and seed orchards will be planted.

--Improved jack pine seed will be available from the Eastern Breeding Districts elite seed orchard and from the Northern and Interlake mass selection orchards. The estimated level of seed production should meet one-third of the planting stock requirements.

--The second generation breeding program for the jack pine program in the Eastern Breeding District will be initiated.

B) Within 10 years (1996-2000)

--The first measurement of all black spruce family tests will be completed and the first roguing of the orchard conducted.

--Improved black spruce seed will be available from the Lake Winnipeg East and Saskatchewan River seed orchards. Estimated level of seed production should meet 1/3 of the planting stock requirements.

--White spruce seed will be available from the Mountain and Saskatchewan River seed orchards. Estimated level of seed production should meet 1/3 of planting stock requirements.

--All jack pine planted in the Pineland, Lake Winnipeg East, Interlake and Saskatchewan River seed zones will be from improved seed collected from the orchards.

C) Within 15 years (2000-2005)

--The second measurement of all black spruce family tests will be completed and the second roguing of the orchards conducted.

--All black spruce planted in the Lake Winnipeg East and Saskatchewan River seed zones will be from improved seed collected from the orchards.

--Over one-half of the black spruce planted in the Interlake and Mountain seed zones will be from improved seed collected from the orchards.

--Over one-half of the white spruce planted in the Mountain, Saskatchewan River and Bisset seed zones will be from improved seed collected from the orchards.

--All jack pine stock will be from genetically improved sources.

## Table 2. IMPLEMENTATION SCHEDULE FOR TREE IMPROVEMENT PROGRAM

| Breeding Zone | 1988/89 | 1989/90 | 1990/91 | 1991/92 | 1992/93 | 1993/94 | 1994/95 | 1995/96 |
|---|---|---|---|---|---|---|---|---|
| **Phase 1** | | | | | | | | |
| Southeast Sb | Plant Family Test | Refill Family Test | Test Maintenance | | | Test Measurement | Test Maintenance | |
| Lake Winnipeg East Sb | Site Prepare Family Test<br>Site Prepare Orchard | Plant Family Test<br>Plant Clone Bank | Refill Family Test<br>Plant Orchard | Test Maintenance<br>Refill Orchard | Refill Orchard | Test Measurement<br>Orchard Maintenance | Test Maintenance<br>Orchard Maintenance | Orch. Mtnce. |
| Saskatchewan River Sb | Select Family Test Sites<br>Complete 450 Plus Trees | Prepare Family Test Sites<br>Prepare Orchard | Plant Family Test<br>Plant Clone Bank | Refill Family Test<br>Plant Orchard | Test Maintenance<br>Refill Orchard | Refill Orchard | Test Measurement<br>Orchard Maintenance | Test Mtnce.<br>Orch. Mtnce. |
| Mountain Sw | Prepare Progeny Test Sites<br>Pollen Progeny Test | Plant Progeny Test<br>Collect Scion Material | Refill Progeny Test<br>Site Prepare Orchard | Test Maintenance<br>Graft Maintenance | Plant Orchard | Orchard Maintenance | Test Measurement<br>Orchard Maintenance | Test Mtnce.<br>Orch. Mtnce. |
| Eastern Pj | Analyze 15 Year Test Data<br>Plant "Elite" Orchard | Orchard Maintenance | Controlled Crosses<br>Orchard Maintenance | Controlled Crosses<br>Orchard Maintenance | Collect Full-sib Seed<br>Collect from Orchard | Analyze 20 Year Data<br>Orchard Maintenance | Polycross Test<br>Expand Orchard | Polycross Test<br>Collect Fr. Orch. |
| Central Pj | Re-establish Clone Bank | | 15 Year Test Measurement | Analyze 15 Year Test | Graft Best Clones | Graft Maintenance | Establish Container Orchard | Orch. Mtnce.<br>20 Year Test Maintenance |
| Northern Pj | | | Thin Mass Selection Orchard | | | Thin Mass Selection Orchard | Collect from Orchard | |
| Interlake Pj | | | | Thin Mass Selection Orchard | | | Thin Mass Selection Orchard | Collect From Orchard |
| **Phase 2** | | | | | | | | |
| Interlake Sb | | Select Plus Trees | Prepare Mass Selection Orchard | Plant Mass Selection Orchard | Refill Orchard | | Thin Mass Selection Orchard | |
| Highrock - Nelson Sb | | | | Select Plus Trees | Prepare Family Test<br>Prepare Orchard | Plant Family Test | Refill Family Test<br>Plant Orchard | Test Mtnce.<br>Refill Orch. |
| Saskatchewan River Sw | | | Select Plus Trees<br>(Grd.) Collect Cones | Select Plus Trees<br>(Aerial) Collect Cones | Prepare Progeny Test<br>Collect Scions | Plant Progeny Test<br>Graft Maintenance | Refill Progeny Test<br>Establish Container Orchard | Test Mtnce.<br>Orchard Mtnce. |
| **Phase 3** | | | | | | | | |
| Mountains Sb | | | | | Select Plus Tree | Prepare Mass Selection Orchards | Plant Mass Selection Orchards | Refill Orchard |
| Boreal Sw | | | | | Select Plus Trees<br>(Grd.) Collect Cones | Select Plus Trees<br>(Aerial) Collect Cones | Prepare Progeny Test<br>Collect Scions | Plant Progeny Test<br>Graft Mtnce. |

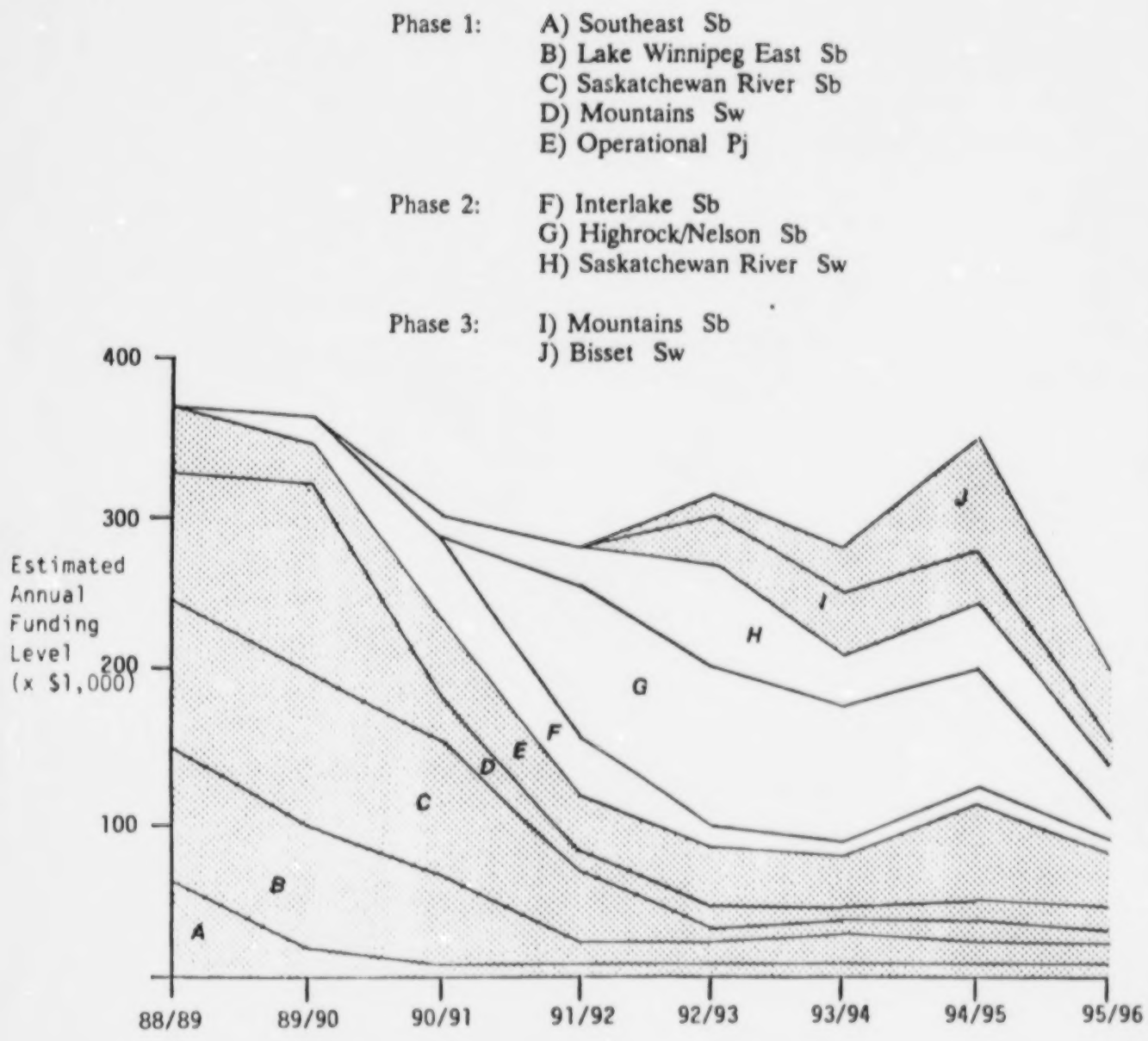



**Figure 21.** Estimated funds required to implement Manitoba's tree improvement program.

## SUPPORTIVE RESEARCH

Tree improvement is a relatively new field of study. There are still a number of techniques which require further development before they can be applied in an operational program. Applied research can enhance the cost efficiency of the program by enabling the production of improved stock at an earlier time frame, lower cost and higher level of genetic gain. The following studies would support the operational tree improvement program and will be conducted if funds become available for applied research projects.

### Potted Seed Orchard Studies

-development of growing and management procedures for white spruce and jack pine. Specific areas of study include: growing procedures; application of stress; use of gibberelic acids; crown management; and cross pollination techniques.

-application of out phase dormancy techniques to accelerate grafted stock development and flower production.

### Vegetative Propagation Studies

-development of operational rooting technique for jack pine. This would enable the immediate production of genetically improved jack pine based on the 20 year results of the existing family tests.

-rejuvenation of semi-mature trees and/or control of maturation. The operational cloning of individuals following a sufficient test period would increase the level of genetic gain achieved.

-refinement of operational rooting procedures for black and white spruce.

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## APPENDIX


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## APPENDIX 1



Table 3. Calculation of Projected Seed Orchard Requirements

1. Black Spruce Seedling Seed Orchard

| Orchard Age | No. of Trees/ha. | Anticipated Annual Seed Production* per tree | per hectare | Orchard Regmt. to Produce 1 Million Seedlings** |
|---|---|---|---|---|
| 10 | 1600 | 250 | 400,000 | |
| 15 | 800 | 750 | 600,000 | 3.3 ha. |
| 20 | 400 | 1750 | 700,000 | |

**based on a 2 seed per seedling sowing rate.
NOTE: Seed production levels from mass selection orchards are expected to be lower.

2. White Spruce Clonal Seed Orchard

| Orchard Age | No. of Trees/ha. | Anticipated Annual Seed Production* per tree | per hectare | Orchard Regmt. to Produce 1 Million Seedlings** |
|---|---|---|---|---|
| 10 | 1020 | 250 | 255,000 | |
| 18 | 510 | 800 | 408,000 | |
| 25 | 204 | 3750 | 765,000 | 2.6 ha. |

**based on a 2 seed per seedling sowing rate.

3. Jack Pine Seedling Seed Orchard
a) Mass Selection Seed Orchard (Initial density 5000 trees/ha,. rogued every 5 years)

| Orchard Age | No. of Trees/ha. | Anticipated Annual Seed Production* per tree | per hectare | Orchard Regmt. to Produce 1 Million Seedlings** |
|---|---|---|---|---|
| 10 | 1250 | 345 | 431,250 | |
| 15 | 625 | 1200 | 750,000 | 2.0 ha. |
| 20 | 400 | 1730 | 692,000 | |

b) Pedigreed Seedling Seed Orchard

| Orchard Age | No. of Trees/ha. | Anticipated Annual Seed Production per tree | PER hectare | Orchard Regmt. to Produce 1 Million Seedlings** |
|---|---|---|---|---|
| 5 | 400 | 345 | 138,000 | |
| 10 | 400 | 1200 | 480,000 | 3.1 ha. |
| 15 | 400 | 1730 | 692,000 | |

**based on a 1.5 seed per seedling sowing rate.

*Anticipated seed production figures were obtained from OMNR, 1987. These figures were used as they were more conservative than other estimates (McPherson et al, 1982; Rudolph, 1981).

## TABLE 4. BLACK SPRUCE CO-OPERATIVE - LAKE WINNIPEG EAST BREEDING ZONE 11.2

| Activity | Abitibi-Price Inc. | Manitoba Forestry Branch |
|---|---|---|
| 1) Plus tree selection grd. | 150 trees | 50 trees (Eastern Region) |
| -aerial | | 250 trees (Head Office) |
| 2) Family Tests-crop production | | Pineland Nursery |
| -establishment & maintenance | 2-4.0 hectare | 1-4.0 hectare site |
| -measurements & analysis | sites | (Head Office) |
| 3) Seed orchard-crop production | | Pineland Nursery |
| -establishment & maintenance | 7.2 hectares | |
| -rogueing and management | 7.2 hectares | |
| 4) Clone bank-grafting | | Pineland Nursery |
| -establishment & management | | 0.7 hectares (Pineland) |
| Distribution of improved seed | 75% | 25% (Eastern Region) |

### IMPLEMENTATION SCHEDULE AND BUDGET ESTIMATES

| Abitibi-Price Inc. | $000 | Manitoba Forestry Branch | $000 |
|---|---|---|---|
| 1987 (Dec.) Select 80 plus trees | | 1987-88 Select 50 plus trees | |
| @ $100/tree | 8.0 | @ $100/tree (ground) | 5.0 |
| 1988 (Jan.) Select 70 plus trees | | Select 250 plus trees | |
| @ $100/tree | 7.0 | -@ $50/tree (aerial) | 12.5 |
| Seed orchard initial SIP | | -Graft 450 trees x 6 grafts | 21.0 |
| 9 ha. @ $900/ha. | 8.1 | Extract 450 seedlots | 4.0 |
| Family test SIP 2-4.0 ha. | | Specific gravity-200 trees | 2.0 |
| @ $1, 100/ha. | 8.8 | | |
| | | 1988-89 Test stock production | 17.0 |
| | | -Family test SIP 1-4.0 ha. | |
| | | @ $1,100/ha. | 4.4 |
| 1989 Plant & map 2-4.0 ha. | | 1989-90 Plant & map 1-4.0 ha. | |
| Tests @ $1,350/ha. | 10.8 | test @ $1,350/ha. | 5.4 |
| Complete SIP of seed | | Orchard stock production | 17.0 |
| orchard 9 ha. | 10.8 | | |
| @ $1,200/ha. | | | |
| 1990 tend & refill 2 tests | | | |
| 8.0 ha. @ $500/ha. | 4.0 | 1990-91 Tend & refill 1 test | |
| Plant & map orchard | | 4.0 ha. @ $500/ha. | 2.0 |
| 7.2 ha-@ $4,200/ha. | 15.9 | | |
| 1991 tend & refill 2 tests | | | |
| 8.0 ha. @ $200./ha. | 1.6 | 1991-92 Tend & refill 1 test | |
| Tend & refill orchard | | 4.0 ha. @ $200/ha. | 0.8 |
| 7.2 ha. @ $750/ha. | 5.4 | | |
| Total 5 year cost estimate | $80.4 | Field Operations | $30.1 |
| | | Pineland | $61.0 |

## TABLE 5. BLACK SPRUCE CO-OPERATIVE - SASKATCHEWAN RIVER BREEDING ZONE 11.5

| Activity | Repap Manitoba Inc. | Manitoba Forestry Branch |
|---|---|---|
| i) Plus tree selection-ground<br>-aerial | 200 trees | 50 trees (Northern Rgn.)<br>200 trees Head Office |
| ii) Family Tests-crop production<br>-establishment and maintenance<br>-measurements and analysis | 3-4.0 ha. sites | Pineland Nursery<br><br>Head Office |
| iii) Seed Orchard-crop production<br>-establishment<br>-maintenance and rogueing | plant 7.3 ha. | Pineland Nursery<br>Site prepare 8.5 hectares<br>7.3 ha. (Head Office) |
| iv) Clone Bank-grafting<br>-establishment and management | | Pineland Nursery<br>0.7 hectares (Pineland) |
| v) Distribution of Improved Seed | 67% | 33% (Northern Region) |

### IMPLEMENTATION SCHEDULE AND BUDGET ESTIMATES

| Repap Manitoba Inc. | $000 | Manitoba Forestry Branch | $000 |
|---|---|---|---|
| 1988 (Jan.) Select 28 plus trees | | 1987-88 Select 50 plus trees | |
| @ $100/tree | 2.8 | @ $100/tree (ground) | 5.0 |
| | | Graft 78 x 6 and Extract Seed | 5.0 |
| 1989 (Jan.) Select 172 plus trees | | 1988-89 Select 200 plus trees | |
| @ $100/tree | 17.2 | @ $50/tree (aerial) | 10.0 |
| Family Test S1P 3-4.5 ha. | | Graft 372 x 6 & | |
| @ $1,100/ha. | 14.9 | Extract Seed | 2.0 |
| | | 1989-90 Test Stock Production | 17.0 |
| | | Seed Orchard S1P 8.5 ha. | 7.6 |
| 1990 Plant & Map 3-4.0 ha. | | 1990-91 Complete Orchard - | |
| Tests @ $1,350/hs. | 16.2 | S1P 8.5 ha. | 10.2 |
| | | Orchard Stock Production | 17.0 |
| 1991 Plant & Map Orchard | | | |
| 7.3 ha. - | 16.1 | | |
| @ $2,200/ha. | | | |
| Tend & Refill 3 Tests | | 1991-92 Tend & Refill Orchard | |
| 12.0 ha. @ $500/ha. | 6.0 | 7.3 ha. @ $750/ha. | 5.5 |
| TOTAL 5 Year Cost Estimate | $73.2 | Field Operations | $30.8 |
| | | Pineland | $61.0 |

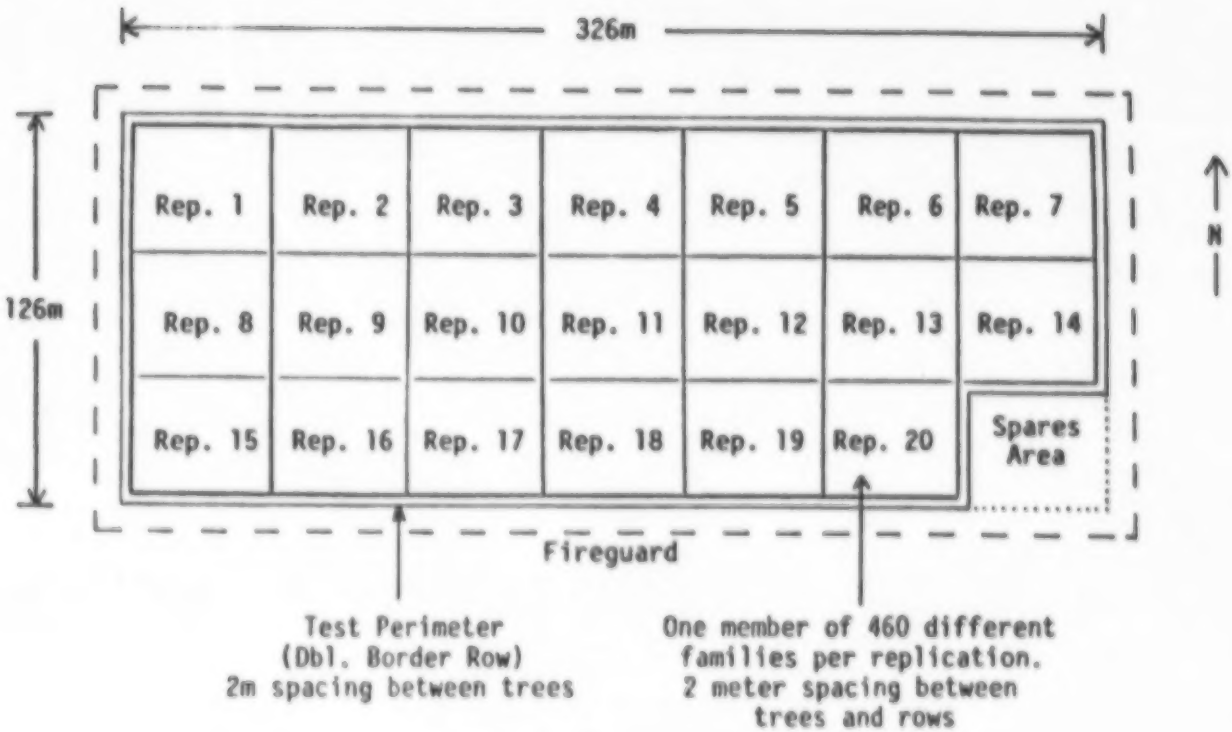



Figure 22: Layout and Design of the McKinnon's Mill Black Spruce Family Test (Zone 11-5).

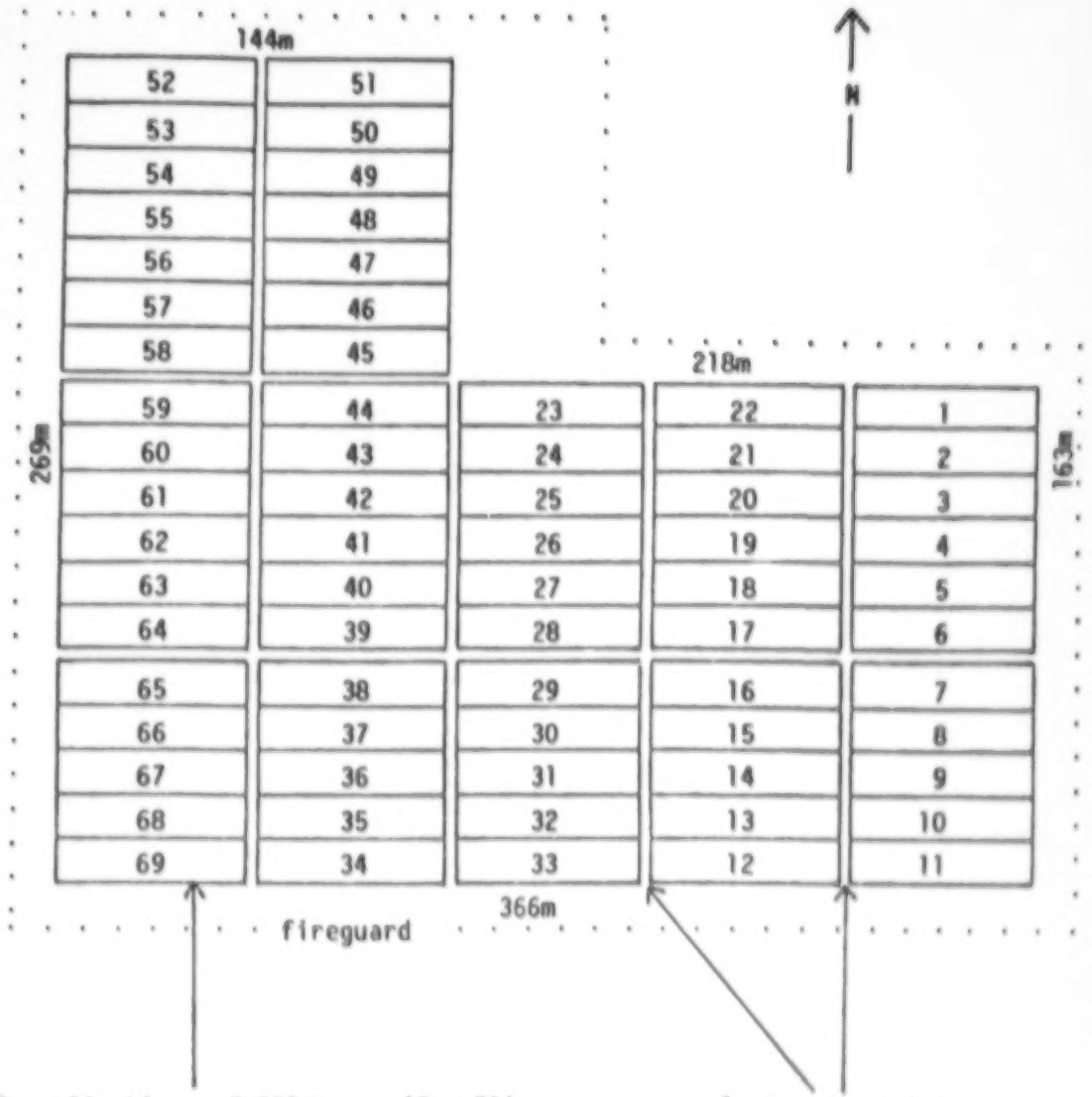



**Figure 23:** Layout and design of the Brightstone Black Spruce seedling orchard

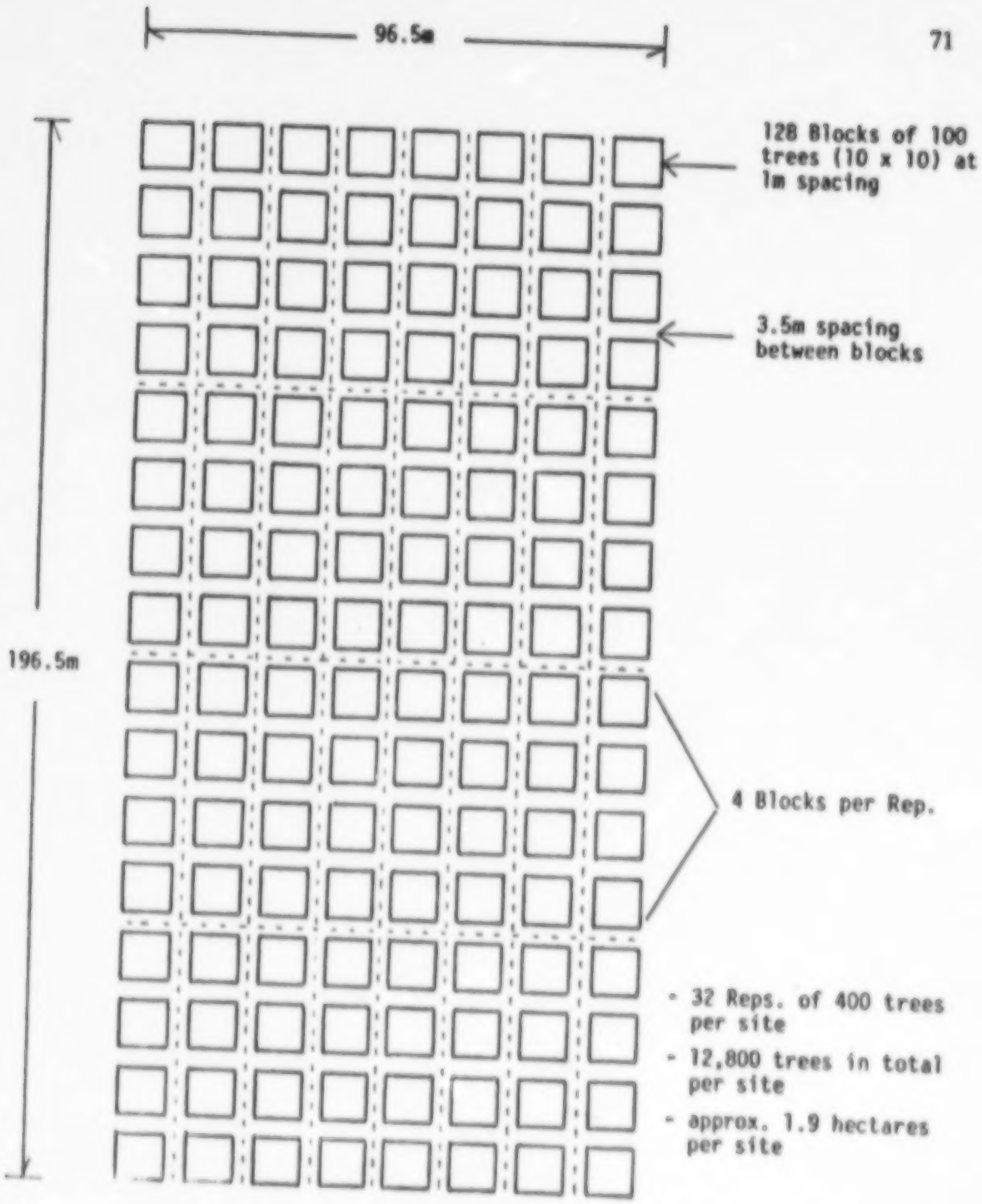
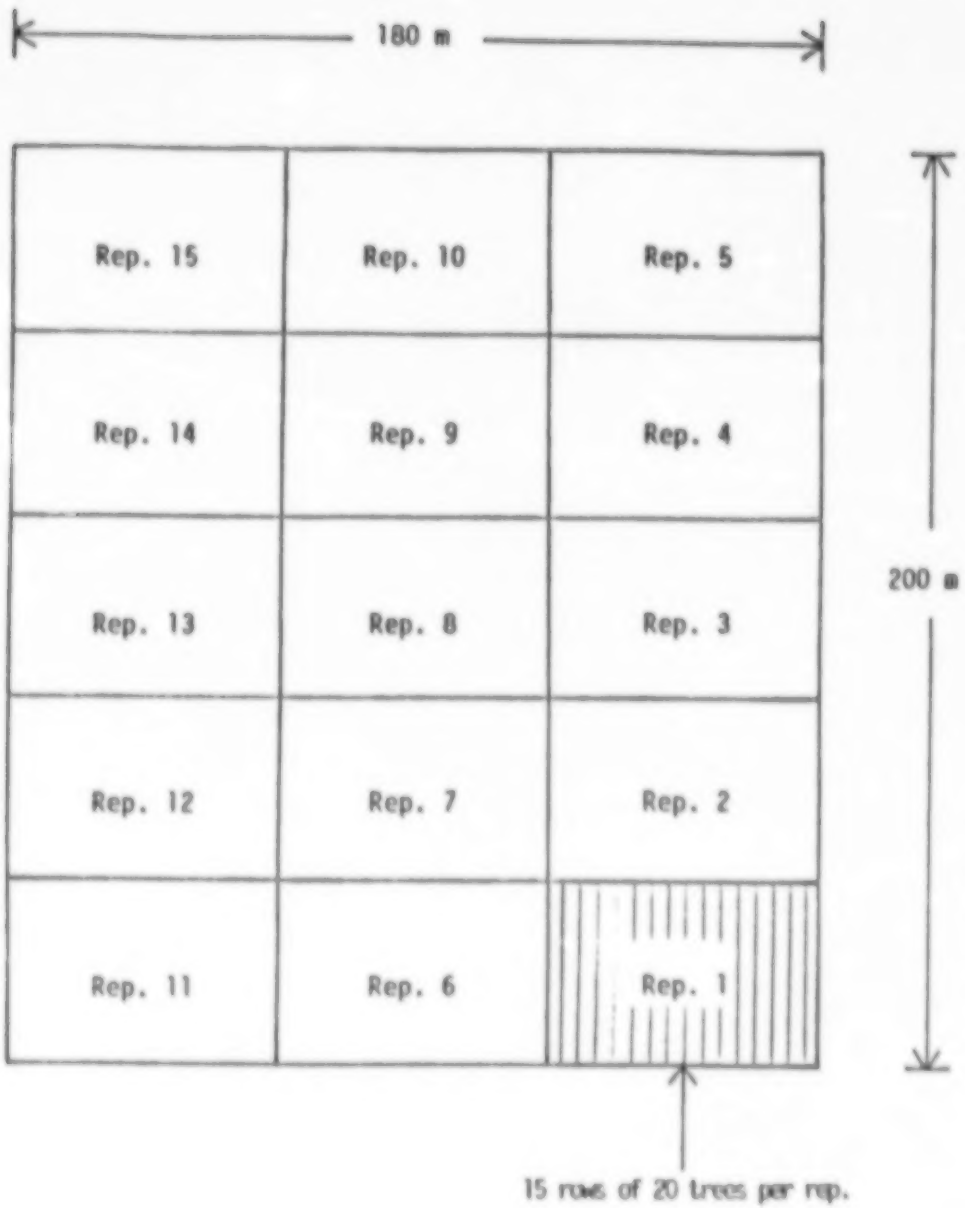
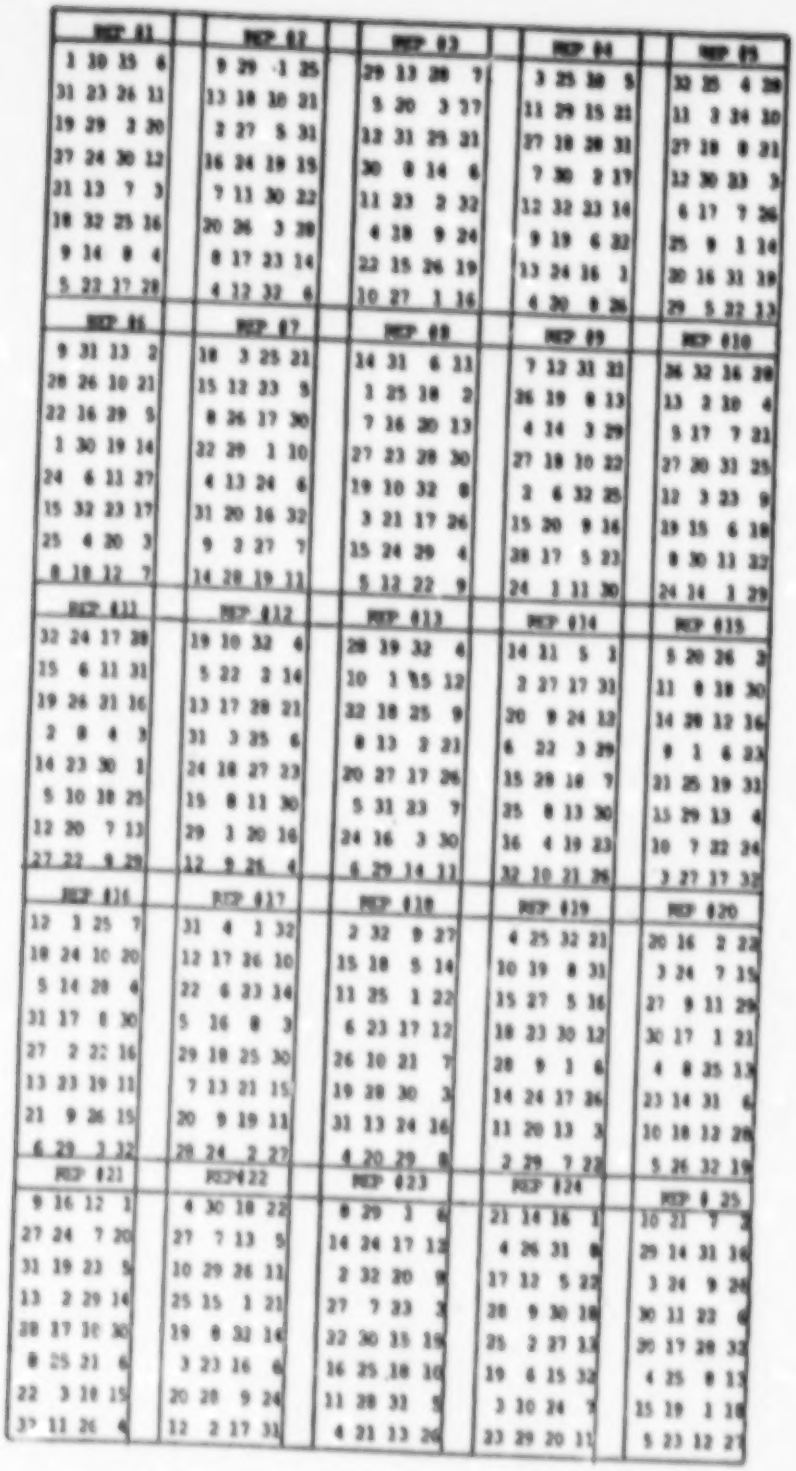

96.5m
128 Blocks of 100 trees (10 x 10) at 1m spacing
3.5m spacing between blocks
196.5m
4 Blocks per Rep.
- 32 Reps. of 400 trees per site
- 12,800 trees in total per site
- approx. 1.9 hectares per site

Figure 24: One of two mass selection Black Spruce Orchards in the Interlake (11-3).




Each replication contains one ramet of 300 different clones, planted at an initial spacing of 2m within rows and 4m between rows. (1250/ha)

**Figure 25:** Layout and Design of a White Spruce clonal seed orchard



| REP 01 | | | | REP 02 | | | | REP 03 | | | | REP 04 | | | | REP 05 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 10 | 15 | 6 | 9 | 29 | 1 | 25 | 29 | 13 | 28 | 7 | 3 | 25 | 10 | 5 | 32 | 25 | 4 | 28 |
| 31 | 23 | 26 | 11 | 13 | 18 | 10 | 21 | 5 | 20 | 3 | 27 | 11 | 29 | 15 | 21 | 11 | 3 | 24 | 10 |
| 19 | 29 | 3 | 30 | 3 | 27 | 5 | 31 | 12 | 31 | 25 | 21 | 27 | 18 | 28 | 31 | 27 | 18 | 8 | 21 |
| 27 | 24 | 30 | 12 | 16 | 24 | 19 | 15 | 30 | 8 | 14 | 6 | 7 | 30 | 3 | 17 | 12 | 30 | 23 | 3 |
| 21 | 13 | 7 | 3 | 7 | 11 | 30 | 22 | 11 | 23 | 2 | 32 | 12 | 32 | 23 | 16 | 6 | 17 | 7 | 26 |
| 18 | 32 | 25 | 16 | 20 | 26 | 3 | 28 | 4 | 28 | 9 | 24 | 9 | 19 | 6 | 22 | 25 | 9 | 1 | 14 |
| 9 | 14 | 8 | 4 | 8 | 17 | 23 | 14 | 22 | 15 | 26 | 19 | 13 | 24 | 16 | 1 | 20 | 16 | 31 | 18 |
| 5 | 22 | 17 | 28 | 4 | 12 | 32 | 6 | 10 | 27 | 1 | 16 | 4 | 20 | 8 | 26 | 29 | 5 | 22 | 13 |
| REP 06 | | | | REP 07 | | | | REP 08 | | | | REP 09 | | | | REP 010 | | | |
| 9 | 31 | 13 | 2 | 18 | 3 | 25 | 21 | 14 | 31 | 6 | 11 | 7 | 12 | 31 | 22 | 26 | 32 | 16 | 20 |
| 28 | 26 | 10 | 21 | 15 | 12 | 23 | 5 | 1 | 25 | 18 | 2 | 26 | 19 | 8 | 13 | 13 | 2 | 10 | 4 |
| 22 | 16 | 29 | 5 | 8 | 26 | 17 | 30 | 7 | 16 | 20 | 13 | 4 | 14 | 3 | 29 | 5 | 17 | 7 | 21 |
| 1 | 30 | 19 | 14 | 22 | 29 | 1 | 10 | 27 | 23 | 28 | 30 | 27 | 18 | 10 | 22 | 27 | 20 | 31 | 25 |
| 24 | 6 | 11 | 27 | 4 | 13 | 24 | 6 | 19 | 10 | 32 | 8 | 2 | 6 | 32 | 25 | 12 | 3 | 23 | 9 |
| 15 | 32 | 23 | 17 | 31 | 20 | 16 | 32 | 3 | 21 | 17 | 26 | 15 | 20 | 9 | 16 | 19 | 15 | 6 | 18 |
| 25 | 4 | 20 | 3 | 9 | 2 | 27 | 7 | 15 | 24 | 29 | 4 | 28 | 17 | 5 | 23 | 8 | 30 | 11 | 32 |
| 8 | 18 | 12 | 7 | 14 | 28 | 19 | 11 | 5 | 12 | 22 | 9 | 24 | 1 | 11 | 30 | 24 | 14 | 1 | 29 |
| REP 011 | | | | REP 012 | | | | REP 013 | | | | REP 014 | | | | REP 015 | | | |
| 32 | 24 | 17 | 28 | 19 | 10 | 32 | 4 | 28 | 19 | 32 | 4 | 14 | 11 | 5 | 3 | 5 | 20 | 26 | 2 |
| 15 | 6 | 11 | 31 | 5 | 22 | 2 | 14 | 10 | 1 | 15 | 12 | 2 | 27 | 17 | 31 | 11 | 8 | 18 | 30 |
| 19 | 26 | 21 | 16 | 13 | 17 | 28 | 21 | 32 | 18 | 25 | 9 | 20 | 9 | 24 | 12 | 14 | 28 | 12 | 16 |
| 2 | 8 | 4 | 3 | 31 | 3 | 25 | 6 | 8 | 13 | 2 | 21 | 6 | 22 | 3 | 29 | 9 | 1 | 6 | 23 |
| 14 | 23 | 30 | 1 | 24 | 18 | 27 | 23 | 20 | 27 | 17 | 26 | 15 | 29 | 18 | 7 | 21 | 25 | 19 | 31 |
| 5 | 10 | 18 | 25 | 15 | 8 | 11 | 30 | 5 | 31 | 23 | 7 | 25 | 8 | 13 | 30 | 15 | 29 | 13 | 4 |
| 12 | 20 | 7 | 13 | 29 | 1 | 20 | 16 | 24 | 16 | 3 | 30 | 16 | 4 | 19 | 23 | 10 | 7 | 22 | 24 |
| 27 | 22 | 9 | 29 | 12 | 9 | 26 | 4 | 6 | 29 | 14 | 11 | 32 | 10 | 21 | 28 | 3 | 27 | 17 | 32 |
| REP 016 | | | | REP 017 | | | | REP 018 | | | | REP 019 | | | | REP 020 | | | |
| 12 | 3 | 25 | 7 | 31 | 4 | 1 | 32 | 2 | 32 | 9 | 27 | 4 | 25 | 32 | 21 | 20 | 16 | 2 | 22 |
| 18 | 24 | 10 | 20 | 12 | 17 | 26 | 10 | 15 | 18 | 5 | 14 | 10 | 19 | 8 | 31 | 3 | 24 | 7 | 15 |
| 5 | 14 | 28 | 4 | 22 | 6 | 23 | 14 | 11 | 25 | 1 | 22 | 15 | 27 | 5 | 16 | 27 | 9 | 11 | 29 |
| 31 | 17 | 8 | 30 | 5 | 16 | 8 | 3 | 6 | 23 | 17 | 12 | 18 | 23 | 30 | 12 | 30 | 17 | 1 | 21 |
| 27 | 2 | 22 | 16 | 29 | 18 | 25 | 30 | 26 | 10 | 21 | 7 | 28 | 9 | 1 | 6 | 4 | 8 | 25 | 13 |
| 13 | 23 | 19 | 11 | 7 | 13 | 21 | 15 | 19 | 28 | 30 | 3 | 14 | 24 | 17 | 26 | 23 | 14 | 31 | 6 |
| 21 | 9 | 26 | 15 | 20 | 9 | 19 | 11 | 31 | 13 | 24 | 16 | 11 | 20 | 13 | 3 | 10 | 18 | 12 | 28 |
| 6 | 29 | 3 | 32 | 28 | 24 | 2 | 27 | 4 | 20 | 29 | 8 | 2 | 29 | 7 | 22 | 5 | 26 | 32 | 19 |
| REP 021 | | | | REP 022 | | | | REP 023 | | | | REP 024 | | | | REP 025 | | | |
| 9 | 16 | 12 | 1 | 4 | 30 | 18 | 22 | 8 | 29 | 3 | 6 | 21 | 14 | 16 | 1 | 10 | 21 | 7 | 2 |
| 27 | 24 | 7 | 20 | 27 | 7 | 13 | 5 | 14 | 24 | 17 | 12 | 4 | 26 | 31 | 8 | 29 | 14 | 31 | 16 |
| 31 | 19 | 23 | 5 | 10 | 29 | 26 | 11 | 2 | 32 | 20 | 9 | 17 | 12 | 5 | 22 | 3 | 24 | 9 | 26 |
| 13 | 2 | 29 | 14 | 25 | 15 | 1 | 21 | 27 | 7 | 33 | 3 | 28 | 9 | 30 | 18 | 30 | 11 | 23 | 6 |
| 28 | 17 | 10 | 30 | 19 | 8 | 32 | 14 | 22 | 30 | 15 | 19 | 25 | 2 | 27 | 13 | 20 | 17 | 28 | 32 |
| 8 | 25 | 21 | 6 | 3 | 23 | 16 | 6 | 16 | 25 | 18 | 10 | 19 | 6 | 15 | 32 | 4 | 25 | 8 | 15 |
| 22 | 3 | 10 | 15 | 20 | 28 | 9 | 24 | 11 | 28 | 31 | 5 | 3 | 10 | 24 | 7 | 15 | 19 | 1 | 18 |
| 37 | 11 | 26 | 4 | 12 | 2 | 17 | 31 | 4 | 21 | 13 | 26 | 23 | 29 | 20 | 11 | 5 | 23 | 12 | 27 |

Figure 26 Interlake Mass Selection Jack Pine Seed Orchard Plantation Layout Diagram Site 3, North Two Rivers

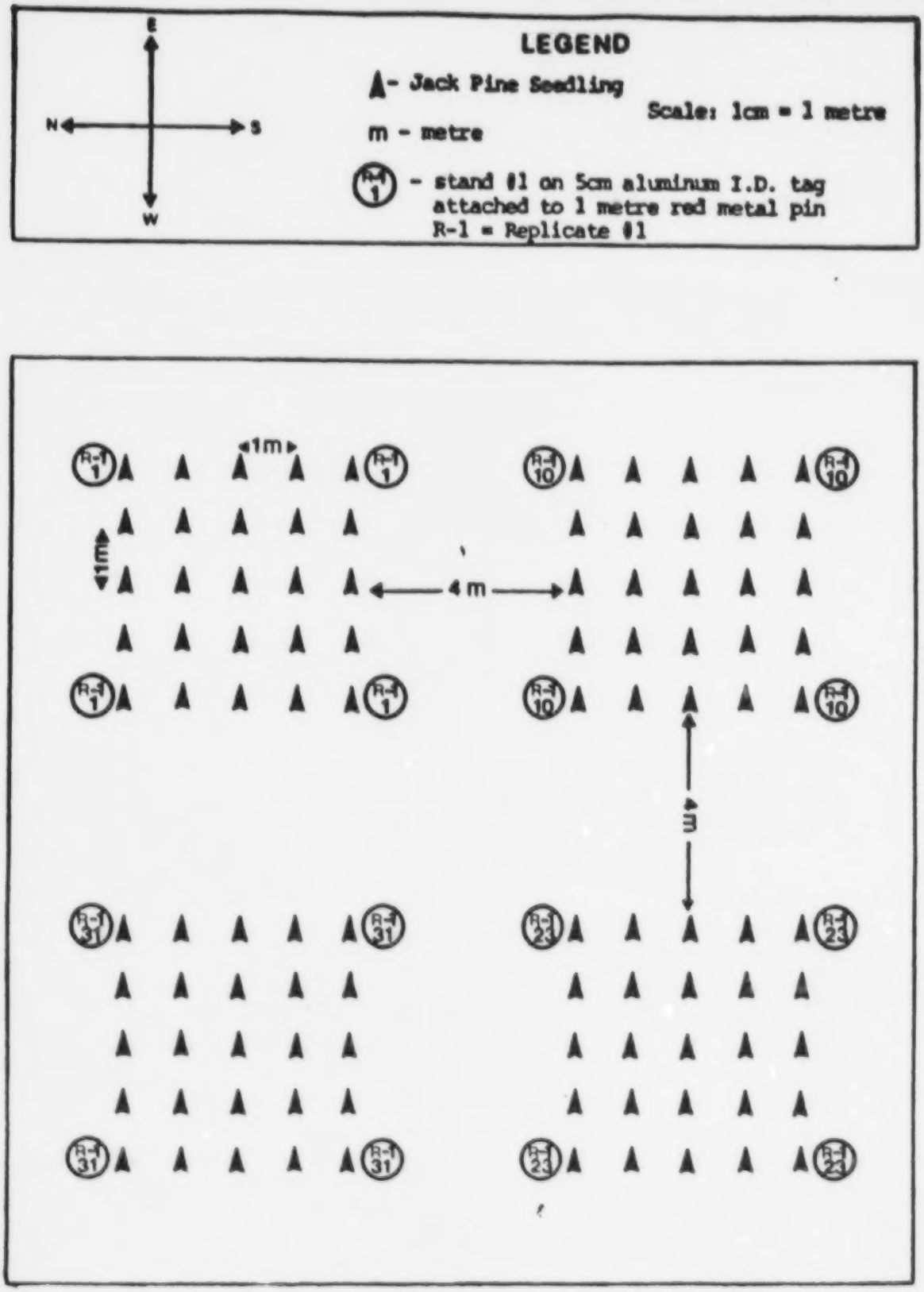



Figure 27 Plot Layout Diagram displaying portion of Replicate 1 of the Interlake Mass Selection Jack Pine Seed Orchard

# APPENDIX

## GLOSSARY

This glossary provides basic definitions of commonly used terms in this report. Most of these definitions are taken directly or modified from Wright (1976) or OMNR (1987).

Asexual Reproduction: Vegetative reproduction or reproduction without fertilization (e.g. rooting of cuttings).

Breeding Hall: A simplified greenhouse used to encourage plant material to flower in order to carry out controlled pollination work.

Breeding Orchard: A collection of selected trees or species established primarily to obtain pedigreed seed from controlled pollinations.

Breeding Zone: A geographic area where selections are made and interbred to create a regional breeding population.

Clinal Variation: A gradual and essentially continuous change of character in a series of continuous populations, frequently, but not always associated with gradual changes in an environment over distance.

Clonal Forestry: The mass propagation of selected and tested clones for production plantations.

Clone: A group of genetically identical plants derived asexually from one individual.

Clone Bank: A collection of grafts or rooted cuttings from selected trees established to preserve genotypes which will eventually be used in controlled pollinations.

Controlled Pollination: Application of pollen from a known source onto a selected receptive female flower, all other pollens being excluded.

Cutting: A detached portion of a plant which, when treated, roots and forms a new complete plant.

Diallel Cross: A mating design that results from crossing all parents in all combinations, including selfs and reciprocal crosses.

Ecotypic Variation: An abrupt or discontinuous change of character associated with a group of individuals adapting to a particular environment (e.g. soil type).

Exotic: A species introduced to an area outside its natural range.

Family: Offspring derived from the seed of a single parental tree as a result of open or controlled pollination (e.g. a group of siblings).

Family Selection: The choosing of parents based on average family performance in a family test.

Family Test: Evaluation and comparison of families grown in one or more environments (see progeny tests).

Flower Induction: Stimulation of the onset of flowering and/or increasing of the number of flowers.

Forest Tree Breeding: Application of the knowledge of genetics in order to develop genetically improved trees.

Full-sibs: Two or more siblings with both parents in common.

Gene: The smallest transmissible unit of genetic material.

Gene Pool: All the genes in a population. More specifically, the genetic basis for the population's continued evolution.

Genetic Gain: The difference in the average performance of offspring derived from selected parents or populations and the performance of a standard or, unselected parental population.

Genetic Variation: Variation resulting from differences in genetic structure (genotype) of individuals.

Genotype: The genetic constitution of an organism.

Geographic Variation: The variation due to genetic differences among populations of a species growing in different regions within its range.

Half-sibs: Two or more siblings with only one parent in common.

Hedge Orchard: Cutting donors pruned low to retard maturation and produce multiple vegetative shoots.

Heredity: The transmission of qualities or characteristics from parents to offspring.

Heritability: The proportion of variation in the population that is attributable to genetic differences among individuals.

Inbreeding: Producing offspring from the mating of relatives.

Inbreeding Depression: The loss ("depression") of vigour or fertility among the offspring of related individuals.

Juvenility: A physiological state in which an individual exhibits characteristics different from those of the mature state, e.g. ease of rooting, no flower production.

Mass Selection: Selection of individuals for breeding or seed collection on the basis of their phenotypic performance.

Maturation: A physiological state in which an individual exhibits characteristics different from those of a young tree, e.g. production of reproductive parts, reduction in growth rate.

Ortet: The original individual of a vegetatively propagated clone.

Outcrossing: The mating of unrelated individuals.

Parent Donor: A selected individual used to supply material for vegetative propagation.

Periodicity: Average number of years between major seed crops.

Persistent Cone Habit: The tendency of cones to remain on the tree after the cone is mature.

Phenotype: The appearance of an individual; a composite of the genotype and the environment and their interaction.

Phenotypic Variation: Variation which is visible to the eye.

Plus-tree: A tree that is phenotypically superior and meets defined selection criteria.

Population: A defined group of individuals that interbreed naturally or by design.

Precocious Flower Habit: The characteristic of producing flowers at a very early age.

Production Orchard: A plantation of selected seedlings or clones established primarily for seed production.

Progeny Test: An evaluation of parents based upon the performance of their offspring (see Family Test).

Provenance: The original geographic source of seed, pollen or propagules.

Ramet: An individual member of a clone derived from the ortet through vegetative propagation.

Roguing: Systematic removal of undesirable individuals from a stand of trees or an orchard.

Rootstock: A plant onto which a scion is grafted.

Scion: A plant part, normally a branchlet, that is grafted onto another plant.

Seed Orchard (production orchard): A plantation of selected seedlings or clones established primarily for seed production.

Seed Source: The specific origin of seed or plants; a tree, stand, or plantation growing at a defined location.

Seed Zone: An area delimited geographically within which seeds may be moved freely without undue risk from environmental stress.

Seed Collection Area: A relatively large, well stocked stand of mature or semi-mature trees with above-average form and vigour that is selected for the collection of source-identified seed from felled trees.

Selection Differential: The difference between the average phenotypic performance of the selected group and the population from which it was taken.

Selfing: Crossing with self; self fertilization; maximum level of inbreeding.

Serotinous Cone Habit: The seeds remain within a persistently closed cone after the seeds mature.

Sub-line: Selections of superior trees that are divided into breeding groups. The breeding is done within, but not between, the groups to continue sub-lines.

Superior Tree (plus tree): A tree that appears phenotypically superior to the average.

Trait: A measurable or describable expression of a gene or group of genes, e.g. height, stem form.

Vegetative Propagation: Asexual reproduction of a plant from vegetative tissue (e.g. rooting of cuttings).

Vegetative Propagule: A plantlet derived from a parent donor by asexual reproduction.